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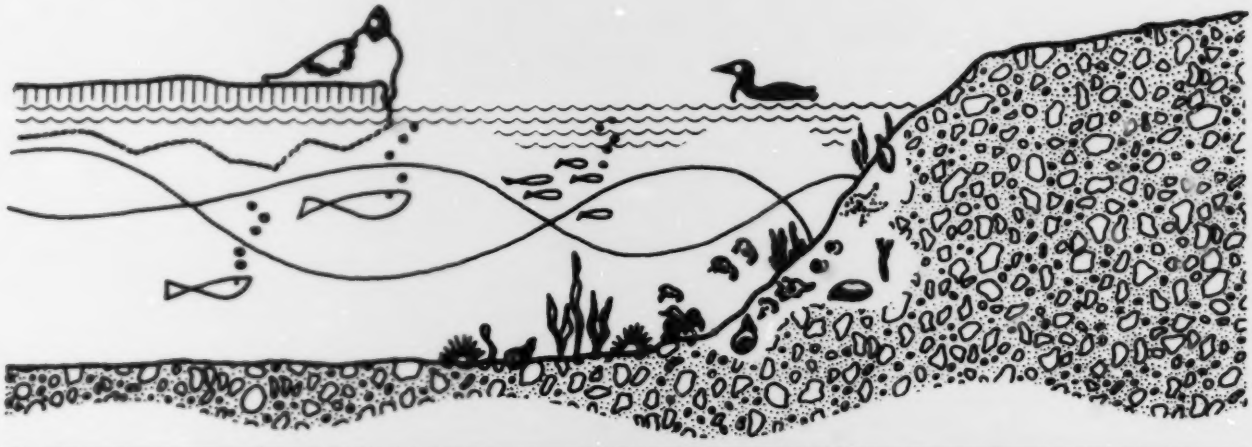

Baffin Island Oil Spill Project

WORKING REPORT SERIES

1982 STUDY RESULTS

The Baffin Island Oil Spill Project

OBJECTIVES

The Baffin Island Oil Spill (BIOS) Project is a program of research into arctic marine oil spill countermeasures. It consists of two main experiments or studies. The first of these, referred to as the Nearshore Study, was designed to determine if the use of dispersants in the nearshore environment would decrease or increase the impact of spilled oil. The second of the two experiments in the BIOS Project is referred to as the Shoreline Study. It was designed to determine the relative effectiveness of shoreline cleanup countermeasures on arctic beaches.

The project was designed to be four years in length and commenced in 1980.

FUNDING

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WORKING REPORT SERIES

This report is the result of work performed under the Baffin Island Oil Spill Project. It is undergoing a limited distribution prior to Project completion in order to transfer the information to people working in related research. The report has not undergone rigorous technical review by the BIOS management or technical committees and does not necessarily reflect the views or policies of these groups.

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Baffin Island Oil Spill Project -1982 Shoreline Component

Prepared for

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Hull, Quebec

March 31, 1983

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The 1982 Shoreline Component of the Baffin Island Oil Spill (BIOS) experiment involved a continuation of the 1980 and 1981 studies and a series of field countermeasures experiments that were conducted in a sheltered, low wave-energy environment. The results of studies completed during 1980 and 1981 in the Cape Hatt area (Fig. 1.1) are discussed in earlier reports (Woodward-Clyde Consultants, 1981a; Owens et al., 1982a). An "Interim Field Report" (dated November 19, 1982) was prepared to document in detail the 1982 field activities; this report (Woodward-Clyde Consultants, 1982) should be consulted for further information concerning the field schedule, the sample procedures, and sample locations. A complete list of reports and publications that have emanated from the Shoreline Component to date is provided on page 1-2.

The specific objectives of the 1982 phase of the Shoreline Component were as follows:

- resample and resurvey intertidal and backshore control plots that were established in 1980 (Fig. 1.2) to evaluate the persistence and weathering characteristics of aged crude oil and of emulsified crude oil on shorelines of differing wave-energy levels,

- resurvey and resample 1981 countermeasures, experiment plots and intertidal control plots at "Crude Oil Point" (Fig. 1.2) to evaluate variations between the countermeasure and the control plots and between the aged crude oil and emulsified crude oil plots,

- sample the intertidal sediments of the beaches in "Z-Lagoon" (Fig. 1.2) prior to the 1982 experiments to determine hydrocarbon levels in the sediments,

- conduct a series of experiments on intertidal and backshore plots in Bay 106 (Fig 1.2) oiled with aged crude oil and emulsified crude oils, using selected countermeasure techniques (the techniques used were: dispersants, low-pressure flushing and mechanical mixing); this series of experiments included the establishment of backshore and intertidal control plots,

- resurvey and resample the beaches in Bays 9 and 11 on Ragged Channel (Fig. 1.2) to monitor the distribution and character of stranded oil.

Observations were made and samples were collected on backshore plots established in Bay 102 (Fig. 1.2) for a series of Norwegian experiments; these are discussed briefly in the report (in Section 2.4).

A series of maps that identify the field sites and the locations of control and experimental plots is given in Figures 1.1, 1.2 and 2.1. The schedule of activities for the period 1980 to 1982 is given in Table 1.1 and a complete listing of the plots, with coded abbreviations, is provided in Table 1.2.

The reports and publications that have been prepared to date from the BIOS Shoreline Component are listed below:

(1) Project Reports:

1980 Final Report (BIOS Working Report No. 80-4)

1981 Interim Field Report

1981 Final Report (BIOS Working Report No. 81-4)

1982 Interim Field Report

1982 Final Report (BIOS Working Report No. 82-4)

(2) Technical Papers:

1982 Arctic Shoreline Countermeasures - Initial results and implications from the BIOS Experiment. Proc. 5th Arctic Marine Oil Spill Program Tech. Seminar, Edmonton, June, 1982, p. 349-362.

1983 Experimental use of dispersants for spill countermeasures on arctic beaches. Proc. Symposium on Oil Spill Dispersants: Five Years of Research, West Palm Beach, FLA, Oct., 1982, (A.S.T.M., Philadelphia, PA) (in press).

1983 Shoreline experiments and the persistence of oil on arctic beaches. Proc. 1983 Oil Spill Conf., San Antonio, TX, Amer. Petroleum Instit., Washington D.C., Pub. No. 4356, p. 261-268.

1983 The BIOS Shoreline Experiment: Results from 1980-82 Field Studies. Proc. 6th Arctic Marine Oil Spill Program Tech. Seminar, Edmonton, June, 1983 (in press).

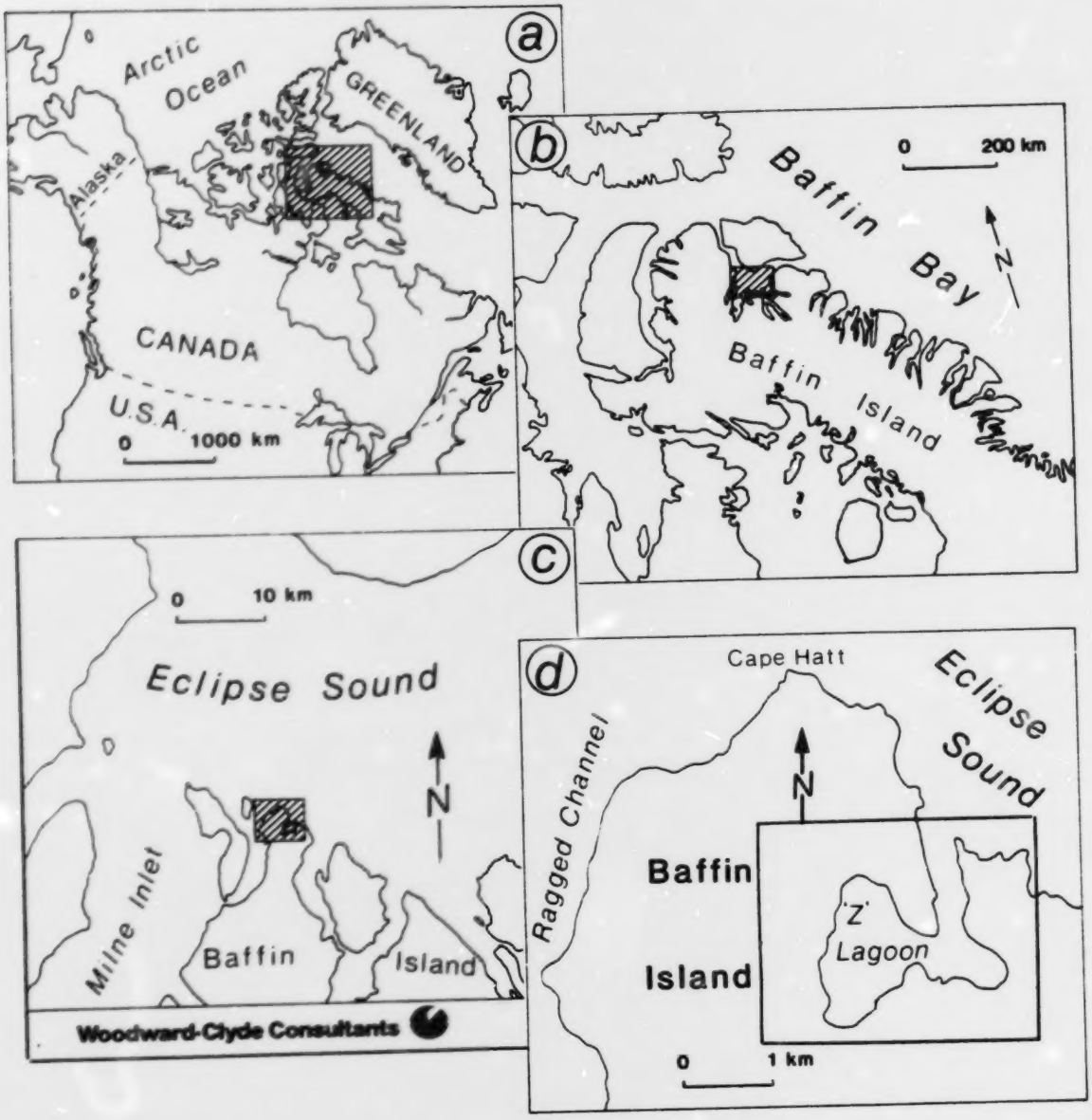


Figure 1.1 Regional location maps. The area within the rectangle in "d" is shown in more detail in Figure 2.1 (page 2-2).

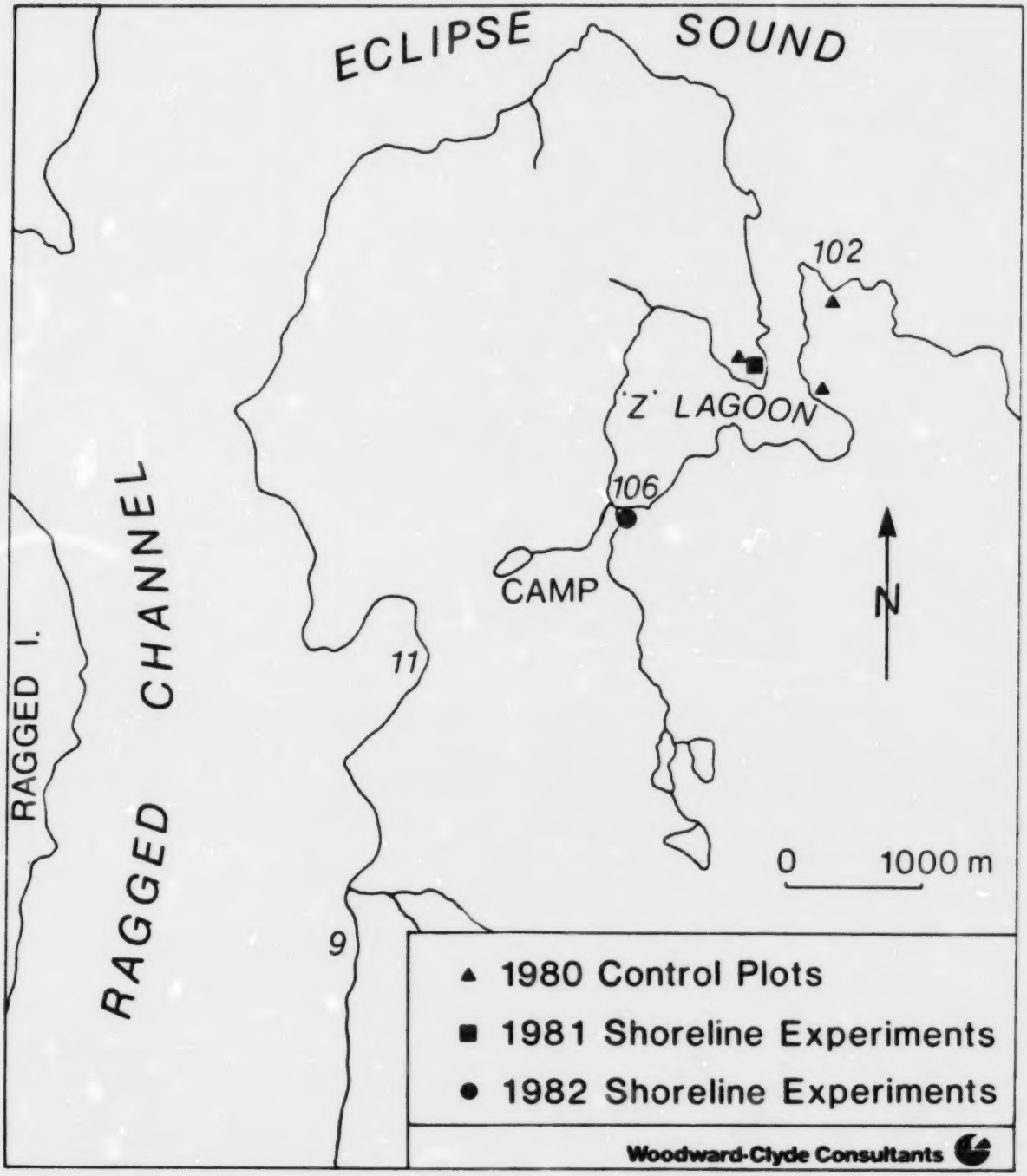


Figure 1.2 Location of the "Z-Lagoon" study sites and of Bays 9 and 11 on the eastern shore of Ragged Channel (Latitude 72°30': Longitude 79°50').

TABLE 1.1 Shoreline Component Experimental Schedule

1980	Control Plots
	• intertidal (exposed and sheltered)
	• backshore
1981	Experiments: Partially Exposed Intertidal Plots
	• burning
	• dispersants
	• gel
	• mixing
	• control
1982	Experiments: Very Sheltered Intertidal Plots
	• dispersants
	• low-pressure flushing
	• mixing (backshore)
	• control

TABLE 1.2 Shoreline Component Experimental and Control Plots

Site	Location	Year Oil Spilled	Plot Designation	Type of Oil	Beach Zone	Activity
"H"	Bay 102	1980	H1	crude	intertidal	control
			H2	emulsion	intertidal	control
"L"	Bay 103	1980	L1	crude	intertidal	control
			L2	emulsion	intertidal	control
"C"	Crude Oil Point	1980	T1	crude	backshore	control
			T2	emulsion	backshore	control
"H"	Bay 102	1980	TE1	crude	backshore	control
			TE2	emulsion	backshore	control
"C"	Crude Oil Point	1981	CC	crude	intertidal	control
			CE	emulsion	intertidal	control
			D(B)C	crude	intertidal	dispersant (BP1100X)
			D(B)E	emulsion	intertidal	dispersant (BP1100X)
			D(E)C	crude	intertidal	dispersant (Corexit 7664)
			D(E)E	emulsion	intertidal	dispersant (Corexit 7664)
			MC	crude	intertidal	mixing
			ME	emulsion	intertidal	mixing
			SC	crude	intertidal	solidifier
			SE	emulsion	intertidal	solidifier
Ragged Channel	Bay 11	1981	-	crude	intertidal	control
"I"	Bay 106	1982	ICC	crude	intertidal	control
			ICE	emulsion	intertidal	control
			ID(B)C	crude	intertidal	dispersant (BP1100X)
			ID(B)E	emulsion	intertidal	dispersant (BP1100X)
			ID(E)C	crude	intertidal	dispersant (Corexit 7664)
			ID(E)E	emulsion	intertidal	dispersant (Corexit 7664)
			IMC	crude	backshore	mixing
			IME	emulsion	backshore	mixing

2.1 INTRODUCTION

During the 1982 field programme, surveys were conducted of the 1980 intertidal and backshore control plots. Backshore control plots (T-1, T-2, TE-1, and TE-2) were resampled for total hydrocarbon content and GC/MS analysis. No topographic surveys of the backshore control plots were undertaken, although a brief description of the plot appearance is included (Section 2.2). Both the low-energy intertidal control plots (L-1 and L-2) and high-energy intertidal control plots (H-1 and H-2) were sampled for total hydrocarbon and GC/MS analyses, and were resurveyed to document topographic changes. A brief description of the physical appearance of these intertidal control plots is included in Section 2.3 along with the results of the beach profile survey.

2.2 1980 BACKSHORE CONTROL PLOTS

Two sets of backshore control plots were established in 1980 for the purpose of monitoring the long-term change of oil content in areas above the intertidal zone. The primary long-term backshore control plots were established at Crude Oil Point (Fig. 2.1) and a secondary set, associated with a Norwegian project, were laid down in the backshore of Bay 102 (Fig. 2.1). One part of the eastern section of the T-1 plot has been used in a separate 1982 experiment that is described by Eimhjellen et al., (1983).

2.2.1 1980 Backshore Control Plots (T-1 and T-2)

Two backshore plots were established in the supratidal area of Crude Oil Point during August 1980. The control plots were an aged crude oil plot (T-1) and a water-in-aged crude oil emulsion plot (T-2). Little visual change has taken place on the surface of these control plots since the original oiling (Fig. 2.2). The plots, which consist primarily of pebbles with gravelly-sand material below the surface, still have a heavy

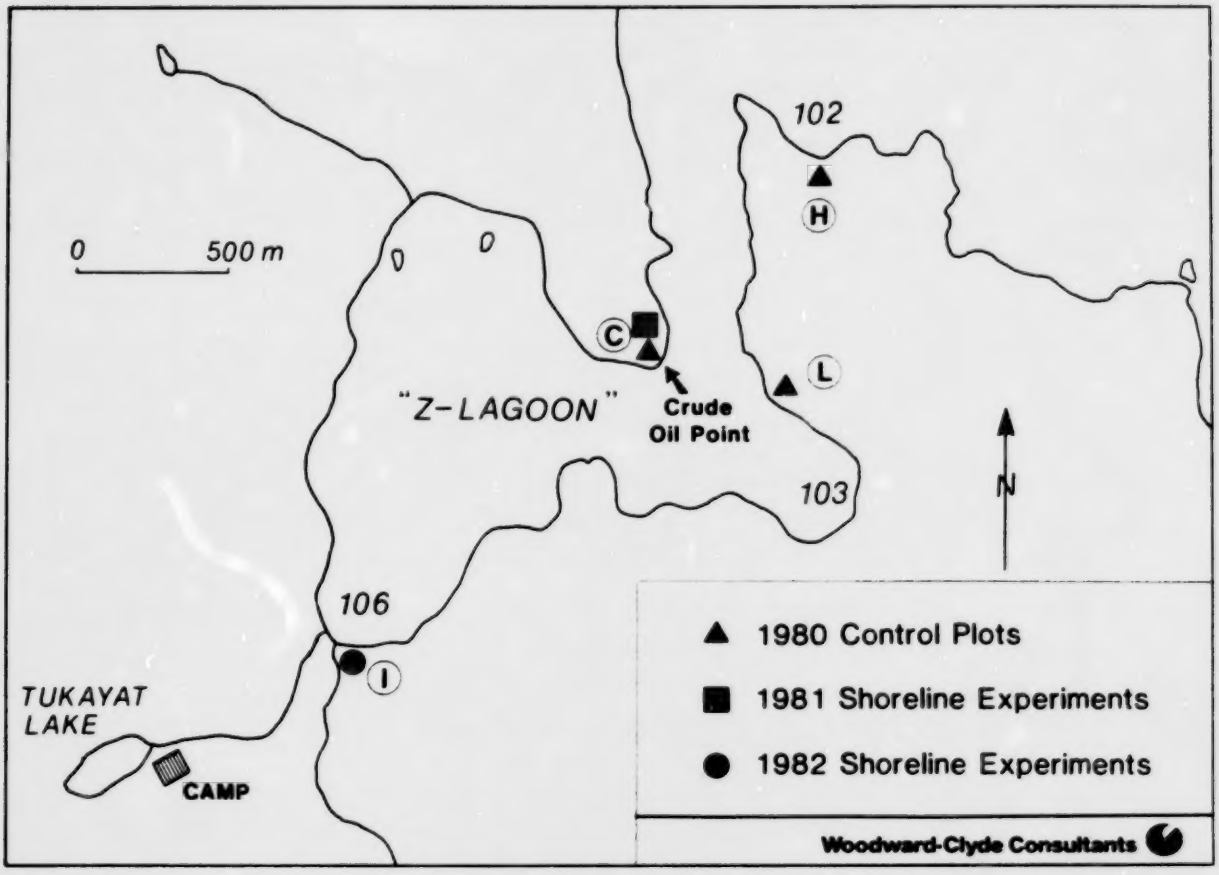


Figure 2.1 Experimental and control locations in the "Z-Lagoon" area. The letters H, C, I and L refer to the sites described in Table 1.2.

oil covering, although weathering has occurred. The only change noticeable during 1982 occurred on plot T-1 where a boat had been inadvertently stored on top of the plot sometime during the 1981/82 winter. As a result, that part of the plot covered by the boat had a greater concentration of wind-blown sand deposited on the surface (Fig. 2.2). Other portions of the plot showed only minor changes as a result of a light dusting from wind-blown material. Neither of these plots has been affected by marine processes since the initial oiling during August of 1980.

Figure 2.2 Aerial photograph (14 August 1982) of Crude Oil Point and the backshore control plots. The light discoloration on T-1 is wind-blown sand that accumulated beneath a boat placed over the plot.

Samples collected for total hydrocarbon content were analyzed by infra-red hydrocarbon analysis (Humphrey, 1983); hydrocarbon content is reported as weight of extracted hydrocarbon per total weight of sample (i.e., mg of oil/kg of sediment) (Table B.1, Appendix B). The results of the total hydrocarbon analyses for years 1980, 1981 and 1982 are presented in Table 2.1. The results indicate that there has been little or no change in sediment oil content since the initial oiling. Concentrations of oil remain high (>15,000 mg/kg) after three years on both the crude oil and emulsion plots.

Some minor changes in total hydrocarbon have occurred over time, although the significance of these are masked by the large variations between samples. The temporal changes are presented in terms of total hydrocarbon contents (Table 2.1) and of the percent change since initial oiling (Table 2.2). The long-term trends suggest that some reduction of

Table 2.1 Total Hydrocarbon Content of the Backshore Control Plots (mg/kg)

		1980				1981		1982	
	DATE	20 Aug	22 Aug	24 Aug	28 Aug	28 July	29 Aug	10 Aug	2 Sept
T-1 (C)	surface	40,100	58,300	33,800	65,800	28,400	34,000	28,300	28,700
	subsurface	23,200	30,000	35,000	17,100	24,300	21,000	15,800	14,700
T-2 (E)	surface	13,100	19,700	12,700	60,000	14,400	16,000	16,700	17,800
	subsurface	15,400	27,100	13,300	58,100	20,600	18,000	16,800	13,500
TE-1 (C)	surface	46,200	49,600	54,200	40,400	29,000	22,000	24,700	23,400
	subsurface	29,400	15,200	32,700	47,700	24,000	19,000	40,400	5,340
TE-2 (E)	surface	51,000	102,000	28,900	58,000	-	24,000	44,900	36,200
	subsurface	17,000	4,600	61,500	500	-	26,000	24,300	29,600

C: CRUDE OIL
E: EMULSION

Table 2.2 Amount of Initial Oil Remaining on Backshore Control Plots (%)

		1980				1981		1982	
		20 Aug	22 Aug	24 Aug	28 Aug	28 July	29 Aug	10 Aug	2 Sept
T-1 (C)	surface	100%	145	84	164	71	85	71	72
	subsurface	100%	129	151	74	105	91	68	63
T-2 (E)	surface	100%	150	97	458	110	122	127	136
	subsurface	100%	176	86	377	134	117	109	88
TE-1 (C)	surface	100%	107	117	87	63	48	53	51
	subsurface	100%	52	111	162	82	65	137	12
TE-2 (E)	surface	100%	200	57	114	-	47	88	71
	subsurface	100%	270	360	29	-	153	143	174

C: CRUDE OIL
E: EMULSION

oil has occurred in the crude oil plot (T-1) and that no change has occurred on the emulsion plot (T-2). There is considerable scatter in both of the data sets that is probably due to sampling variation; however, generally consistent lower hydrocarbon content values on the crude oil plot (T-1) over the past two sampling seasons (1981, 1982) suggest a small long-term reduction in oil on the plot (particularly in the subsurface), although this reduction cannot be quantitatively estimated. The reason for this apparent reduction is not clear, but possibly could be due to leaching of oil deeper into the sediments. The geochemical analyses indicate that weathering and microbial degradation are not responsible for producing the observed change.

Some important differences in total hydrocarbon content exist between the two plots. Surface oil concentrations are noticeably higher on the crude oil plot (approximately 28,000 mg/kg) than on the emulsion plot (approximately 18,000 mg/kg). This difference is largely a result of initial retention values, where considerably more oil was retained on the crude oil plot. Subsurface oil values fall in a similar range in both plots (13,500 to 14,700 mg/kg), although the distribution of oil with depth is more uniform in the emulsion plot (T-2) than in the crude oil plot (T-1) because of differences in surface concentrations; this difference between oil profiles in the two plots has existed since the initial (1980) sample period.

Results of the geochemical analysis (Boehm, 1983) are presented in Table C.1, in Appendix C, and the changes in diagnostic ratios are presented for the three years of sample collection in Table 2.3. The results indicate that most of the physical weathering of the plots occurred prior to the 1981 sampling period and that little physical weathering has taken place subsequent to 1981 (Table 2.3a). The ALK/1SO ratio, which provides an index of biodegradation of the oil, has shown no significant change over the study period, indicating that microbial degradation of the oil is insignificant (Table 2.3b).

Table 2.3a Saturated Hydrocarbon Weathering Ratio (SHWR) Changes on Backshore Control Plots (surface)

	1980 (INITIAL)	1980 (8 DAYS)	1981	1982
T-1 (CRUDE)	2.4	2.2	1.6	1.6
T-2 (EMULSION)	1.9	1.8	1.6	1.3
TE-1 (CRUDE)	2.2	2.2	1.5	3.4
TE-2 (EMULSION)	2.1	2.1	1.2	2.0

Table 2.3b Alkane/Isoprenoid Ratio (ALK/ISO) Changes on Backshore Control Plots (surface)

	1980	1980	1981	1982
T-1 (CRUDE)	2.4	3.0	2.1	2.4
T-2 (EMULSION)	2.6	2.3	2.4	2.4
TE-1 (CRUDE)	2.4	2.8	3.1	2.6
TE-2 (EMULSION)	2.6	2.6	2.4	2.5

2.2.2 1980 Backshore Control Plots (TE-1 and TE-2)

During 1980, two backshore plots were established in Bay 102 for the purpose of conducting microbiological studies in an oiled beach environment. The following year (1981), it was observed that these plots had been slightly submerged during spring tides in combination with high waves. Analysis of the total hydrocarbon content of the sediments, however, indicated that very little change had occurred as a result of the submergence (Owens *et al.*, 1982a). An additional storm-surge event apparently occurred during the late summer of 1981 and had a much more significant effect on these control plots. The plots were buried on the landward side by a mixture of sand/cobble material and were eroded on the seaward side as a result of a lowering of the beach elevations in the intertidal zone. The burial depth on the landward part of the plots is approximately 10 to 15 cm. The heavy oil concentrations on the plots provided cohesion to the sediment so that these plots were slightly more resistant to the erosional processes.

The quantitative results of total hydrocarbon content and GC/MS analyses are suspect because (1) the plots were of smaller dimenensions, (2) the plot surfaces were irregular, creating areas of pooled oil, and (3) sampling areas were restricted due to other ongoing experiments within the plots. Consequently, the sampling probably does not provide a good representation of the oil distribution within the plot as a whole. The sample results reflect these limitations and show considerable scatter.

Total hydrocarbon results for these two plots are presented in Table 2.1 and, as in the other backshore control plots (T-1 and T-2), show continued high levels of oil content (20,000 to 40,000 mg/kg). It is not possible to make meaningful comparisons between the crude oil and emulsion plots or between the surface and subsurface hydrocarbon contents because of the scatter in the data.

Evaluations of year-to-year changes in oil content (Table 2.2) are similarly difficult to make because of the variability in sample results. The data suggest, however, an overall reduction in oil content, most of which occurred between the 1980 and 1981 sample collections. The change may be a partial result of mechanical removal of oil by high swash events or a result of additional physical weathering.

The geochemical analyses (Table C.1) and the diagnostic ratios (Table 2.3) suggest that (a) no significant biodegradation of the oil has occurred, and (b) most physical weathering occurred between the 1980 and 1981 sample collections (the high SHWR for fall 1982 sample is probably due to cross-contamination from other more recently oiled plots).

2.3 1980 INTERTIDAL CONTROL PLOTS

During 1980 four control plots were established within the intertidal zone for the purpose of long-term monitoring. These plots included both an aged crude oil plot and a water-in-oil emulsion plot in Bay 102, which is exposed to comparatively high wave-energy levels, and Bay 103, which is exposed to comparatively low wave-energy levels.

2.3.1 High-Energy Intertidal Control Plots (H-1 and H-2)

Previous studies of these plots have indicated that little oil remained on the beaches prior to 1982 (Owens et al., 1982a) and no visible oil was apparent on the test plots during 1982 (Fig. 2.3). Some oil was apparent along the storm-swash line in the upper part of Bay 102. This oil could have been reworked from the two intertidal plots or from the backshore control plots (TE-1 and TE-2) as well as from backshore plots established during 1981 (see Section 2.4).

The across-shore profiles for plot H-1 are shown in Figure A-1 (Appendix A) for the survey conducted during 1982 as well as for the 1980 and 1981 surveys. Comparison of the profiles indicates that

(1) significant erosion occurred between the 1981 and 1982 surveys although the plot section of the beach was relatively stable,

(2) most of this erosion occurred above the high-water line suggesting that a storm event was largely responsible,

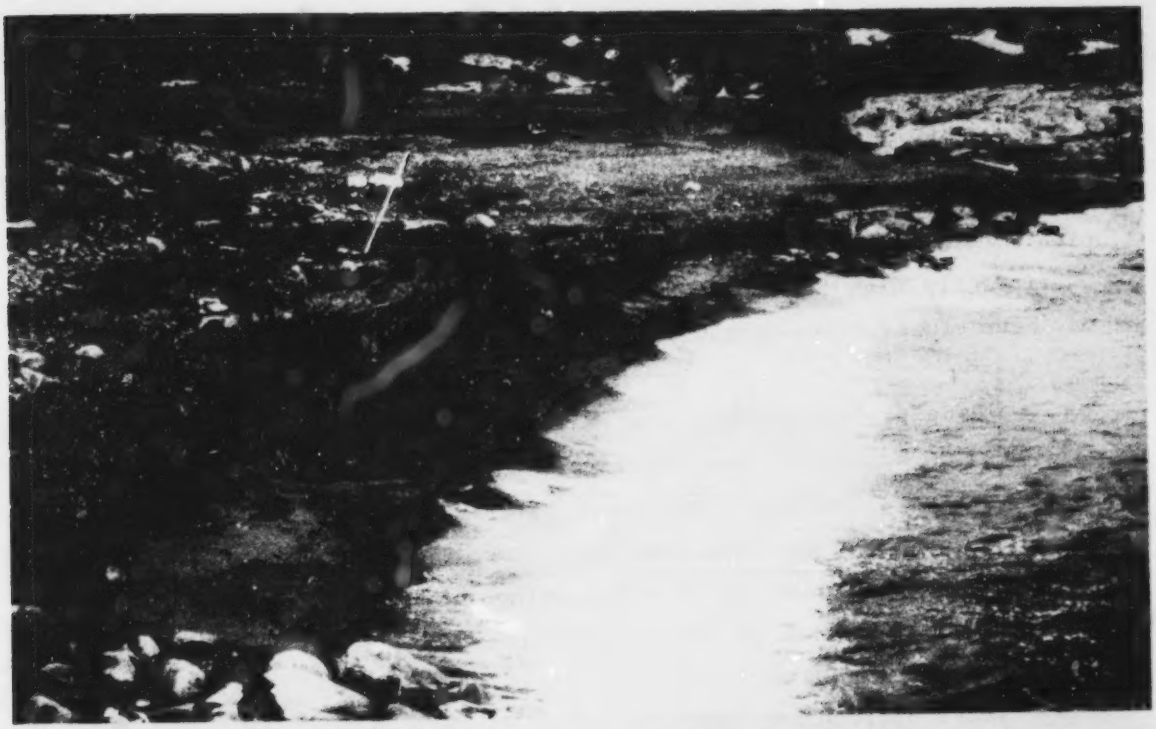
(3) net erosion amounting to a 17 cm average lowering of the plot surface has occurred over the survey period; profile sweep-zone thickness was approximately 30-40 cm over the plot.

Across-shore profile changes for plot H-2 are shown in Figure A-1 (Appendix A) and indicate similar trends to those that occurred on Plot H-1. Comparison of the three years of survey data indicates that

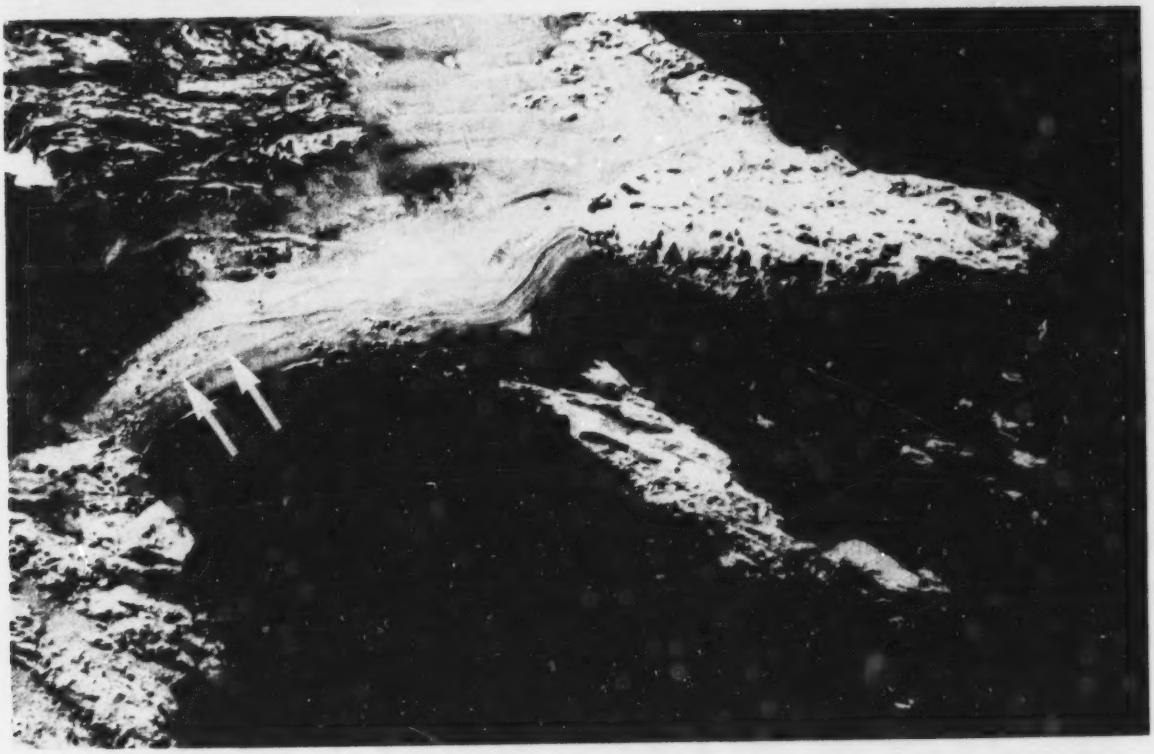
(i) net erosion occurred between the 1981 and 1982 surveys although, again, the plot area of the beach was relatively stable and even showed local areas of accretion,

(ii) most of the erosion occurred above the high-water line, primarily on profile line A,

(iii) the beach has undergone net erosion since the original oiling in 1980, with an average lowering of the plot surface by 19 cm; the maximum profile sweep-zone thickness was approximately 50 cm with an average thickness of 30 cm.



(a)



(b)

Figure 2.3 (a) Ground view of high-energy beach plots, 23 August 1980.

(b) Aerial view of plots, 14 August 1982.

The net changes that have occurred on the Bay 102 beaches have been caused by storm-related events. The most severe storm of the study period occurred during the fall of 1981 (after the last survey) and generated storm-swash lines 2 m above mean water level, approximately 1 m above predicted higher high-water levels. The storm water levels were sufficiently high to inundate several of the backshore control plots and may have caused cross-contamination of the plots in Bay 102.

These profile changes are extremely significant to the removal of oil on the beaches. The relatively large changes that have occurred between surveys indicate that beach material is highly mobile, thereby, facilitating the mechanical breakdown and dispersal of the stranded oil. The strong wave action and the resulting dynamic sediment movement have caused complete removal of oil from the test plots.

Total hydrocarbon contents of sediment samples collected from the plots are presented in Table 2.4 with summary results in Table 2.5. The results show that no oil remains on either the surface or subsurface of these plots. It is of interest to note that the majority of the oil was removed from these plots within two days of the initial oiling (Table 2.5), although detectable amounts were present at the onset of the second open-water season (Tables 2.4 and 2.5). Subsequent wave action effectively removed the remaining oil during the 1981 open-water season.

Geochemical analysis results for the intertidal control plots are presented in Table C.1 (Appendix C) with diagnostic ratios for the survey period summarized in Table 2.6. The SHWR results from 1981 and 1982 indicate higher values than those obtained from the 1980 samples. The increase in the SHWR for 1981 may be due to cross-contamination by oil from other, more recently, oiled backshore plots. In contrast to the evaporative weathering ratio, the ALK/ISO ratio has shown significant change since the initial oiling and these changes indicate that biodegradation of the oil occurred after the last sample set from 1980 on the crude plot and after the 1981 samples on the emulsion plot. The total amount of resolved hydrocarbons is very small, however, and the quantitative amount of the biodegradation cannot be estimated.

Table 2.4 Total Sediment Hydrocarbon Content (mg/kg), High Energy Control Plots (H-1 and H-2)

PLOT H-1 AGED CRUDE, HIGH ENERGY

	1980				1981		1982	
	23 Aug	25 Aug	27 Aug	31 Aug	28 July	29 Aug	10 Aug	2 Sept
UPPER surface	20,400	10	70	370	150	tr	0	0
UPPER subsurface	10,400	560	1,800	27,400	1,480	0	0	0
MIDDLE surface	11,600	190	50	3,200	tr	0	0	0
MIDDLE subsurface	14,400	8,800	16,200	100	tr	0	0	0
LOW surface	77,400	10	160	10	-	0	0	0
LOW subsurface	11,600	550	2,200	2,600	-	0	0	0

PLOT H-2 EMULSION, HIGH ENERGY

UPPER surface	15,900	10	100	50	3,630	0	0	0
UPPER subsurface	28,000	20	110	-	770	0	0	0
MIDDLE surface	1,900	20	10	3	0	0	0	0
MIDDLE subsurface	1,300	10	30	4	0	0	0	0
LOW surface	23,200	10	10	9	0	0	0	0
LOW subsurface	2,200	10	10	8	0	tr	0	0

Table 2.5 Amount of Initial Oil Remaining on Intertidal Control Plots (%)

		1980				1981		1982	
		INITIAL	+2 DAYS	+4 DAYS	+8 DAYS	BEGIN YR 2	END YR 2	BEGIN YR 3	END YR 3
H-1 (C)	surface	100%	< 1	< 1	3	< 1	0	0	0
	subsurface	100%	27	55	81	4	0	0	0
H-2 (E)	surface	100%	< 1	< 1	< 1	9	0	0	0
	subsurface	100%	< 1	< 1	< 1	2	0	0	0
L-1 (C)	surface	100%	30	23	38	27	10	18	28
	subsurface	100%	34	47	90	32	31	61	55
L-2 (E)	surface	100%	7	5	4	1	4	2	< 1
	subsurface	100%	6	1	6	6	14	0	0

C: CRUDE
E: EMULSION

Table 2.6a Saturated Hydrocarbon Weathering Ratio (SHWR) Changes on the Intertidal Control Plots

	1980 (INITIAL)	1980 (8 DAYS)	1981	1982
H-1 (C)	1.3	1.8	2.0	1.8
H-2 (E)	1.0	1.2	2.1	1.7
L-1 (C)	2.5	2.5	1.1	1.3
L-2 (E)	2.1	2.0	1.0	1.1

Table 2.6b Alkane/Isoprenoid Ratio (ALK/ISO) Changes on the Intertidal Control Plots

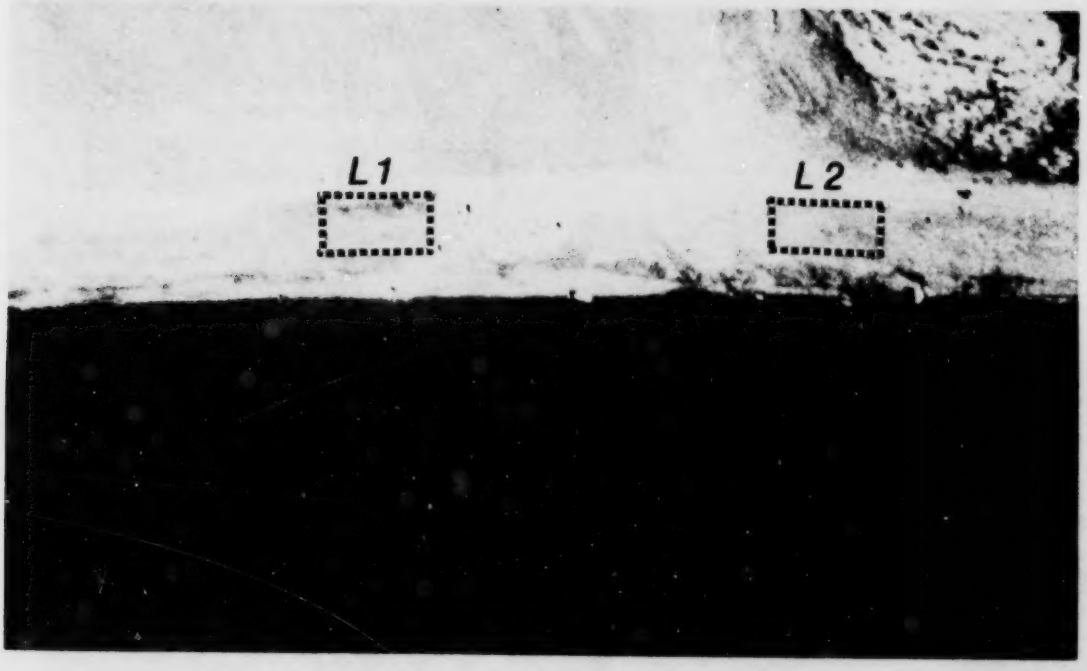
	1980 (INITIAL)	1980 (8 DAYS)	1981	1982
H-1 (C)	2.6	2.8	1.6	1.4
H-2 (E)	3.0	2.4	2.4	1.4
L-1 (C)	2.4	2.5	1.9	1.7
L-2 (E)	2.7	2.8	1.1	1.1

C: CRUDE OIL
E: EMULSION

2.3.2 Low-Energy Intertidal Control Plots (L-1 and L-2)

There was little difference in the appearance of these low-energy control plots between 1981 and 1982 (Fig. 2.4). In 1982 plot L-1, the aged crude oil plot, showed 50-75 percent covering of oil in the upper part of the plot and less than a 20 percent covering of oil in the lower part of the plot. Subsurface oil contents in the upper part of the plot could be seen (Fig. 2.5), whereas in the lower part of the plot, no visible oil was apparent except on the underside of some of the larger pebbles.

(a)

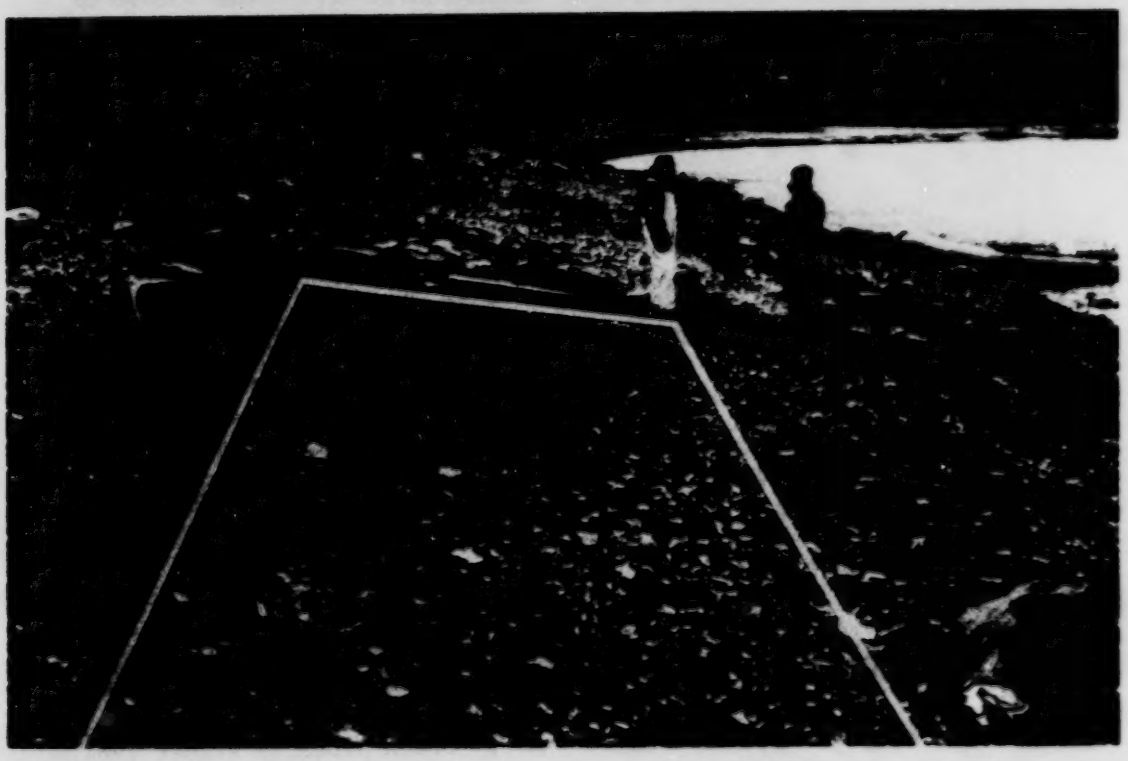


(b)

Figure 2.4 (a) Aerial views of low-energy beach plots, 7 August 1981, and

(b) 14 August 1982.

(a)



(b)

Figure 2.5 (a) Ground view of L-2, August 22 1980, and

(b) L-1, 10 August 1982

Plot L-2, the water-in-oil emulsion, showed almost no visible oil on either the surface or the subsurface (Fig. 2.4b). Occasional oil spots were present on some of the larger pebbles, but these accounted for less than 10 percent covering of the plot. The undersides of some larger pebbles had an oil covering, but the sandy-gravel matrix was generally free of visible oil. A light visible sheen on the water surface could be produced by mixing the sediments with the water.

The across-shore beach profiles for plots L-1 and L-2 are shown in Figure A-1 (Appendix A). Only portions of previous profiles are shown because the year-to-year changes that occurred on the profiles were small (<5 cm: this small amount of change is normal for low-energy beaches of this type). Only subtle indications of the presence of 1982 ice mounds (see Owens et al., 1982a, Fig. 3.6) were noted, probably because of the relatively late date of the 1982 surveys.

Total hydrocarbon analyses (Table 2.7) indicate that relatively high concentrations of oil (approximately 5,000 mg/kg) persist on the crude oil plot (L-1), but that there is virtually no oil on the emulsion plot (L-2). Subsurface oil concentrations on L-1, the crude oil plot, are comparable to the surface concentrations, whereas no oil is present in subsurface sediments of the emulsified oil plot (L-2).

Analysis of the amount of initial oil remaining on the plot (Table 2.5) shows that a significant amount (approximately 60 percent) of oil has been removed from L-1 even though the total hydrocarbon contents of the sediment remain high. Although there is scatter in the data, the trends indicate that oil concentrations in the subsurface have been reduced less than those of the surface (Table 2.5). The trends also show that most of the reduction in volume of oil on L-2 occurred within two days of the initial oiling and that subsequent changes have been small, even though virtually all the oil has been removed.

The geochemical analyses and diagnostic ratios (Table 2.6) provide additional insight into the weathering processes. Changes in the SHWR, an indicator of evaporative weathering, were large between the first and

Table 2.7 Total Sediment Hydrocarbon Content (mg/kg), low-energy intertidal control plots (L-1 and L-2)

PLOT L-1 AGED CRUDE, LOW ENERGY

		1980				1981		1982	
	DATE	21 Aug	23 Aug	25 Aug	29 Aug	28 July	29 Aug	10 Aug	2 Sept
UPPER	surface	6,700	4,600	4,500	5,700	4,790	2,520	2,150	2,580
	subsurface	8,800	8,000	7,700	12,600	5,770	5,390	15,700	8,480
MIDDLE	surface	8,700	4,700	2,500	7,700	2,920	1,090	1,750	11,500
	subsurface	13,000	900	9,400	18,300	7,470	4,690	9,830	13,200
LOW	surface	36,000	6,100	4,700	6,000	6,460	1,290	5,540	440
	subsurface	24,600	6,900	4,700	10,800	1,820	4,510	3,030	3,840

PLOT L-2 EMULSION, LOW ENERGY

UPPER	surface	1,300	210	80	370	70	170	0	0
	subsurface	500	110	20	20	tr	190	0	0
MIDDLE	surface	4,500	320	340	10	290	170	0	40
	subsurface	2,200	60	10	160	130	160	0	0
LOW	surface	3,700	140	40	10	50	100	230	0
	subsurface	-	50	10	50	70	130	0	0

second years (1980 and 1981) but were subsequently small between the second and third years (1981 and 1982). Both the crude oil plot (L-1) and emulsion plot (L-2) showed similar weathering trends. Analysis of the ALK/1SO ratio, an indicator of microbial degradation, suggests that biological weathering of the oil has occurred on both plots, but to a slightly greater extent on the emulsion plot (L-2). The changes occurred primarily between the first and second years (1980 and 1981) with only a small change between the second and third years (1981 and 1982).

2.4 NORWEGIAN BACKSHORE TEST PLOTS

During 1981, five backshore emulsion plots were established for testing the effect of countermeasures techniques on the microbiological decomposition of stranded oil (Owens et al., 1982a). These experiments were directed by Norwegian personnel (Eimhjellen et al., 1983). These plots were submerged during late August 1981 by a combination of spring tides and high wave swash wave levels. At that time, the plots were buried by approximately 10 to 15 cm of sediment. Further submergence of these plots occurred during the early fall of 1981 prior to freezeup; additional material was deposited on some of the plots, whereas other plots experienced erosion. The layout of the plots is shown in Figure 2.6, and mean burial depths for each plot are included in Table 2.8. Erosion completely removed all visible oil from the surface and subsurface of Plot D, the southernmost of the plots. This plot had been treated with a solidifying material during 1981 and despite the asphalt-like nature of the

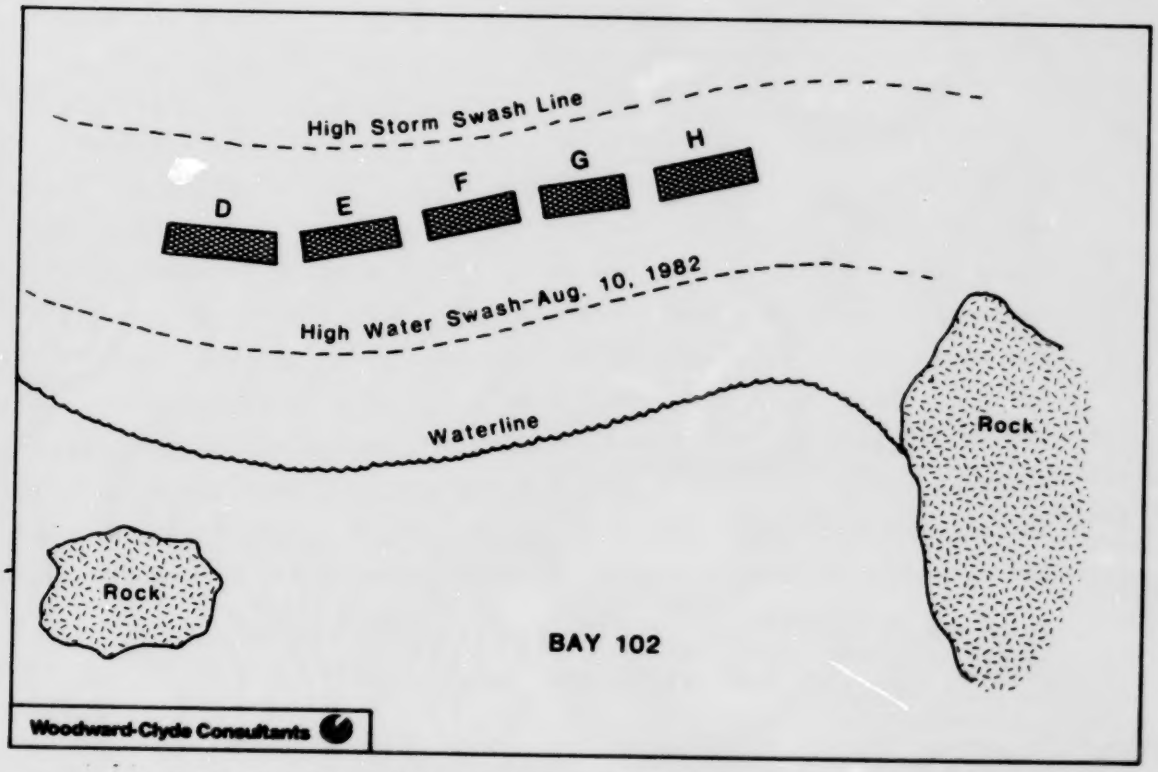


Figure 2.6 Sketch map of the location of the 1981 Norwegian backshore emulsion plots in Bay 102.

Table 2.8 Total Hydrocarbon Content of the Bay 102 Norwegian Backshore Test Plots

PLOT		t-h (mg/kg)	MEAN BURIAL DEPTH (cm)	OIL LAYER THICKNESS (cm)
D	subsurface	0	0	0
E	oil layer	15,900		
	below oil layer	0	4	7
F	oil layer	21,600		
	below oil layer	210	8	8
G	oil layer	19,800		
	below oil layer	50	14	6
H	oil layer	20,200		
	below oil layer	2,020	10	10

solidified oil-sediment mass, this material was completely absent in the 1982 survey. Other plots showed visible buried oil layers beneath a clean sand layer (Table 2.8). The maximum mean burial depth was 14 cm, and the mean maximum thickness of the buried oil layers was 10 cm.

Total hydrocarbon values are high (15,000 to 20,000 mg/kg) on all plots (Table 2.8) with the exception of Plot D, on which all oil was removed by beach erosion. Geochemical analysis results are presented in Table 2.9. The SHWR, with values in the 1.8 range, suggests that some evaporative weathering has taken place, but the ALK/1SO ratios are high on all except one plot, indicating the bio-degradation on these plots has been minimal. Plot E, a plot mixed with a rototiller, showed lower ALK/1SO ratios, suggesting that some biodegradation may have occurred since the original oiling. This plot also has the thinnest sediment cover (average burial depth 4 cm), and the lower ALK/1SO ratio may reflect an increase in biodegradation processes near the surface in comparison to those at depth.

Table 2.9 Geochemical Analysis Results: 1981 Norwegian Backshore Plots

PLOT	DATE	DIAGNOSTIC RATIOS SHWR	ALK/ISO
E	27 Aug 82	1.8	1.9
F	27 Aug 82	1.8	2.6
G	27 Aug 82	1.8	2.5
H	27 Aug 82	1.7	2.4

The results of the Norwegian Study are reported elsewhere (Eimhjellen et al., 1983), and these indicate that the fertilization did enhance the rate of biodegradation of the oil even though it had been buried.

The burial of oil on these plots illustrates the complex interaction that can take place between oceanographic processes and sediment redistribution in the shore zone. Nine test plots were established within this bay (Bay 102) during 1980 and 1981; some experienced significant sediment erosion while others experienced sediment accretion. The complexity of these sediment movements illustrates the difficulty of predicting such events even with a good environmental data base and is indicative of the element of uncertainty that accompanies all spill situations.

2.5 SUMMARY

Observations and data for the (1980) control plots now extend for a period of three years, and it is possible to make preliminary evaluations of the fate or persistence of the oil that was laid down on the intertidal and backshore plots. In particular,

- virtually no change in oil content has occurred on any of the backshore test plots (T-1, T-2, TE-1, TE-2, Norwegian Plots: E, F, G, H) which have not been subjected to wave action,

- data from the intertidal control plots indicate significant changes in oil content as a function of wave exposure: (a) plots exposed to comparatively high wave-energy levels during the open-water season (H-1, H-2) have no oil remaining after two years, and (b) plots exposed to comparatively low wave-energy levels (L-1, L-2) have variable amounts of oil remaining on the plots,

- in the case of the low-energy plots, almost complete removal of emulsified oil from Plot L-2 appears to be a function of the type of oil and of the substrate; fine sediments and associated high-water tables initially prevented oil penetration and adhesion, thereby facilitating natural dispersion of oil from this plot despite low wave-energy levels,

- comparison of diagnostic weathering ratios shows (i) evaporative weathering was significant on the backshore and low-energy intertidal plots prior to the 1981 sample set with little or no change between 1981 and 1982 (the high-energy plot data may be misleading due to possible cross-contamination), and (ii) biodegradation has occurred on the intertidal zone plots, but is not significant on the backshore plots; the biodegradation is significant on the intertidal plots primarily after the first year, with little or no change between 1981 and 1982,

- beach sediment mobility is important in the redistribution of oil and ultimately its persistence: surveyed profiles show relatively extensive sediment redistribution on the high-energy beaches of Bay 102, but more stable conditions and fewer changes in beach morphology on the low-energy control plots site.

3.1 INTRODUCTION

The experimental design, the countermeasures techniques, and the initial (1981) results of the experiments conducted at Crude Oil Point are fully documented in the BIOS Working Report 81-4 (Owens et al., 1982a).

Field activities during 1982 involved resampling of each plot, with the exception of the two solidifier plots (SE and SC: Fig. 3.1). Samples were collected on two separate occasions, three weeks apart, for total hydrocarbon analyses and for geochemical analyses. The data sets derived from these analyses are given in Appendices B and C respectively. In addition, beach profiles established in 1981 were resurveyed on one occasion, and the composite plots of all 1981 and 1982 profiles are presented in Appendix A.

3.2 BEACH PROFILE SURVEY

Profiles 0 through 140 (Fig. 3.2) were resurveyed on August 11, 1982 to provide information on beach changes between the 1981 and 1982 open-water seasons. The plotted profiles from the 1982 survey have been superimposed on the earlier (1981) profiles, and these are presented in Appendix A (Fig. A.2).

A comparison of profile elevations between August 8, 1981, immediately following the experiments, and August 11, 1982, (Fig. 3.3) shows a pattern of erosion on profiles 0, 20, 80, and 120, with accretion or burial on profiles 40, 60, 100 and 140. The elevation changes are generally less than 10 cm in magnitude except on profiles 80 and 140 where they reach up to 20 cm of erosion and accretion respectively.

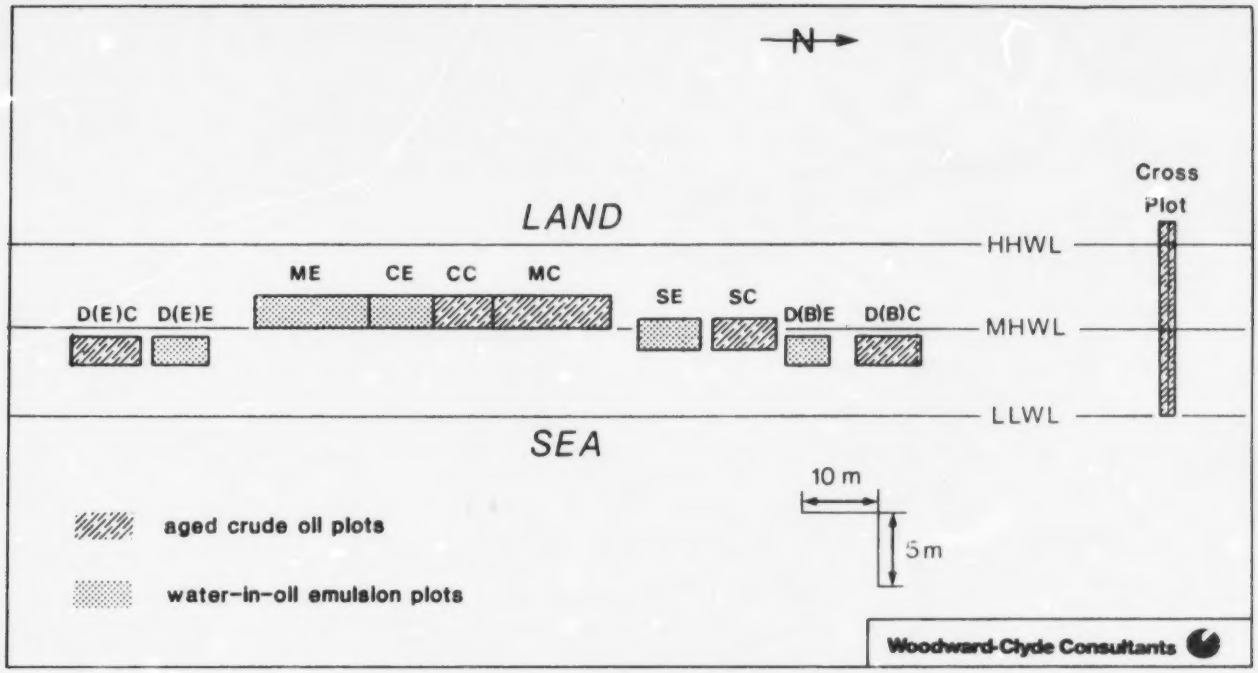


Figure 3.1 Layout of 1981 countermeasures experiment and control plots at Crude Oil Point. The location of the plots is shown on Figure 1.2, and plot identification codes are given in Table 1.2.

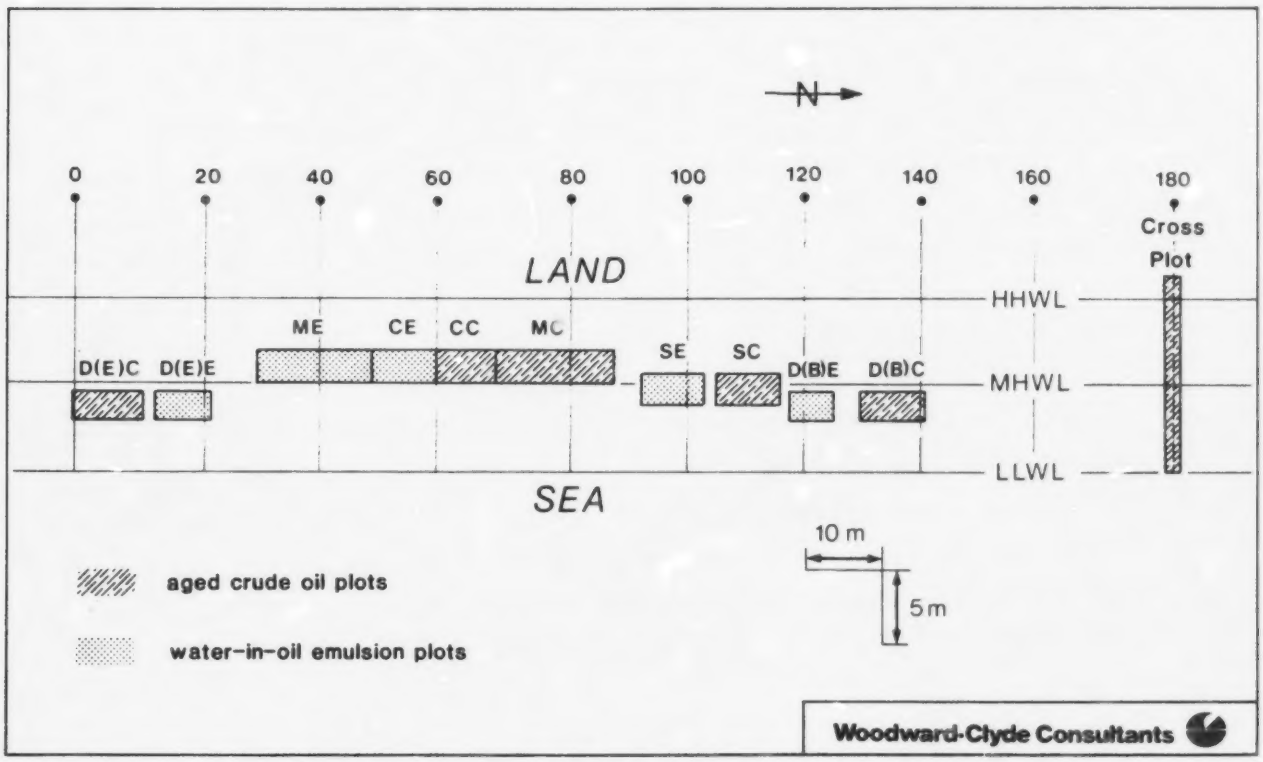


Figure 3.2 Location of beach profiles with reference to the countermeasures experimental plots.

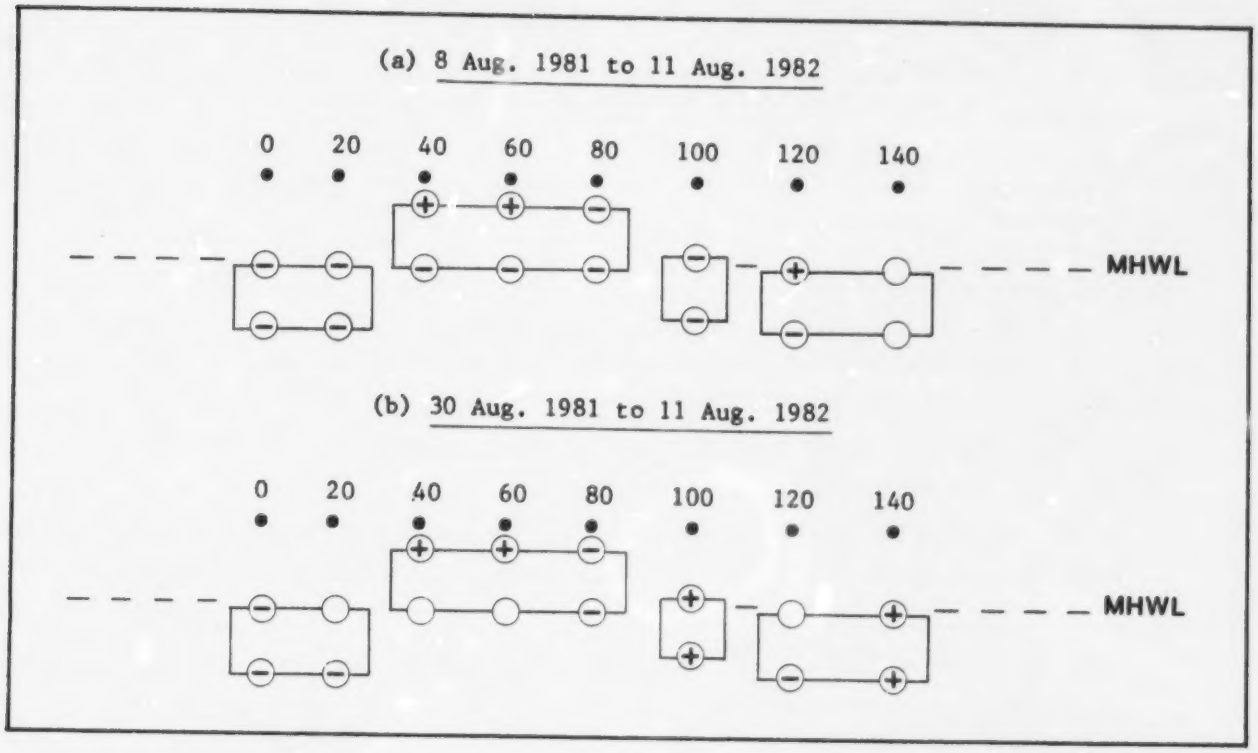


Figure 3.3 Beach elevation changes at cross-over points of profiles on oiled plots. Open circle indicates not discernable change, + indicates accretion and - indicates erosion.

There has been vertical erosion in the range of 5 to 20 cm along the base of each plot between the last survey of 1981 (August 30) and the 1982 survey (Fig. 3.3b) in all cases except profile 140, which shows no change. The erosion is least on the northerly profiles (5 cm on 80, 100 and 120), and greatest on the most southerly profiles (15 and 20 cm respectively on 0 and 20).

The pattern of change is less regular along the tops of the plots, with erosion on profiles 0, 20, 80 and 100, and accretion on profiles 40, 60 and 120. Profile 140 again showed no discernable change.

There is no evidence or dominant pattern to the beach changes. The study beach has been subject to very localized sediment redistribution in which small but significant differences may occur alongshore at a scale of less than 20 m and at an across-shore scale of less than 2 m.

3.3 RESULTS OF TOTAL HYDROCARBON ANALYSES

The analytical data are presented in Appendix B. The data are summarized in Table 3.1, which also includes the results from the 1981 analyses.

3.3.1 Surface Samples

The data show that the surface sediments on the plots had a range of values between 0 and 300 mg/kg at the time of the first 1982 survey and between 0 and 500 mg/kg at the time of the second survey, with mean values of 124 and 160 mg/kg respectively. Expressed alternatively, the sample analyses produced no oil-in-sediment values greater than 0.05 percent, with the majority being less then 0.02 percent oil-in-sediment by weight.

The four dispersant plots had little oil in the surface sediments at the last sample date in 1981, and these low values were replicated during the 1982 sampling periods. The control (CC and CE) and mixing (MC and ME) plots exhibited high values at the end of 1981 (range 930 to 19,000 mg/kg: mean 6232 mg/kg), but these were significantly reduced by the first sample set of 1982 (range 90 to 300 mg/kg: mean 195 mg/kg). These values remained low through to the second 1982 sample set (range 80 to 500 mg/kg: mean 205 mg/kg).

The reduction of oil content between the last 1981 set and the 1982 sets is particularly evident when the data are considered in terms of the percent of oil remaining from the original oil volume on each plot (Table 3.2). By September 1982, only 2 of the 8 plots had more than 1 percent of the original oil remaining on the plot.

Despite the overall lowering of oil content, there exists some differences between plots. In 1982 more oil remained on the control and mixing plots than remained on the dispersant plots, with the exception of D(E)E. Similarly, more oil remained on the two D(E) than on the D(B) plots. As all of the oil volumes are low, the only significant difference that exists between plots is that no oil remained on either of the two D(B) plots, whereas small amounts of oil were detected on each of the other six

Table 3.1 Results of Total Extractable Hydrocarbon Analyses - 1981 Countermeasures Control and Experimental Plots (mg/kg)

CODE		1981				1982	
		Pre-Test	Post-Test	+8 Days Aug 15	+40/41 Days Sept 16	Aug 10	Sept 02
CC	surface	21,000	*	17,000	3,110	300	80
	subsurface	3,020	*	1,500	150	3,380	220
CE	surface	12,000	*	21,700	930	90	500
	subsurface	1,060	*	380	110	390	300
MC	surface	21,000	28,000	4,980	19,000	160	140
	subsurface	3,020	10,000	16,000	1,800	1,240	2,280
ME	surface	12,000	21,000	19,000	1,890	230	100
	subsurface	1,060	290	310	190	1,070	450
D(E)C	surface	25,000	6,070	440	360	80	90
	subsurface	300	5,940	2,390	170	900	50
D(E)E	surface	24,000	20,000	2,370	330	130	370
	subsurface	150	513	290	tr	170	260
D(B)C	surface	4,310	10,000	tr	t-	0	0
	subsurface	*	3,130	3,190	tr	30	0
D(B)E	surface	7,370	2,740	70	tr	0	0
	subsurface	70	4,400	80	tr	0	0

* no sample

Table 3.2 Percent of Oil Remaining through Time from Initial Oiling - Surface Samples (a plus sign indicates an increase in volume)

CODE	1981			1982	
	Pre-Test	+8 Days	+40/41 Days	Aug 10	Sept 02
CC	100%	81	15	1.4	0.4
CE	100	+181	8	0.8	5
MC	100	24	81	0.8	0.7
ME	100	+158	16	1.9	0.8
D(E)C	100	1.8	1.4	0.3	0.4
D(E)E	100	10	1.4	0.5	1.5
D(B)C	100	0	0	0	0
D(B)E	100	0.9	0	0	0

countermeasures or control plots. The D(E) plots are the most exposed, with respect to wave-energy levels, as they are located at the northern end of the study beach (Fig. 3.1) adjacent to Eclipse Sound (Fig. 2.1). It is not directly evident whether the lower values are a result of initial low loading values,the dispersant effectiveness, or of the exposure to wave action, although the fact that the initial reduction of oil on both plots was high (Table 3.2) suggests that dispersant effectiveness may be the more significant factor.

3.3.2 Subsurface Samples

At the time of the last sample period in 1981, only the MC plot had an oil volume greater than 200 mg/kg; however, in the the first sample set of 1982, five plots (CC, CE, MC, ME and D(E)C) had values greater than 200 mg/kg. At the time of the second 1982 sample set, 5 plots again had values greater than 200 mg/kg (CC, CE, MC, ME and D(E)E).

Subsurface volumes of oil-in-sediment were greater than surface volumes on six of the eight plots on August 10, and on three of the eight plots on September 2, 1982; whereas in September, 1981, all of the subsurface values were less than the surface values.

No distinct patterns of change through time or between plots are evident except that (a) the volume of oil retained in the subsurface of the MC plot remains high, and (b) the two D(B) plots continue to show little or no oil present (Tables 3.1 and 3.3). Except for the MC plot, the values of oil-in-sediment by weight are low, less than 0.05 percent. Although oil was initially driven into the subsurface sediments following the tests on all except the ME plot (Table 3.1), the subsequent natural physical reworking of oiled sediments during the 1981 and 1982 open-water seasons resulted in some reduction of oil content. The patterns are somewhat erratic, however, except for the two D(B) plots and the MC plot.

As noted above (Section 3.3.1), the location of the two D(B) plots with respect to wave exposure from Eclipse Sound may account for the lower oil-in-sediment values on these plots.

Table 3.3 Percent of Oil Remaining through Time from Initial Oiling - Subsurface Samples (a plus sign indicates an increase in volume)

	1981			1982	
CODE	Pre-Test	+8 Days	+40/41 Days	Aug 10	Sept 02
CC	100%	50	5	+112	7
CE	100	36	10	33	28
MC	100	+530	60	41	76
ME	100	29	18	16	42
D(E)C	100	+797	57	+300	17
D(E)E	100	+193	<1	+113	+173
D(B)C	100*	+1063	<1	10	0
D(B)E	100	+114	<1	0	0

* sample lost: value assumed to be 300 mg/kg

3.4 RESULTS OF GEOCHEMICAL ANALYSES

The data discussed in this section are presented in Appendix C.

3.4.1. Evaporative Weathering Ratio (SHWR)

All of the plots were more highly weathered by the end of August, 1982, when compared to the mid-September 1981, results (Table 3.4). The two D(B) plots, although devoid of oil in the total hydrocarbon samples (Section 3.3), showed small oil concentrations in the GC/MS samples (Table C. 2), and these latter were characterized by residual kerosene/light fuel oil components that affected the ratio. These components were present as the dispersant BP 1100X contains a hydrocarbon solvent.

The progressive evaporative weathering is evident on each of the control (CC and CE) and mixing (MC and ME) plots (Table 3.4); this trend is evident but less regular on the two D(E) plots. The change in ratios on the control plots was most significant in 1981 (3.0 to 1.6 and 3.0 to 1.4 on the crude and emulsion plots respectively) with a smaller change between +40 days in 1981 and August 29 in 1982 (1.6 to 1.1 and 1.4 to 1.0). By contrast, the changes on the mixing plots were lower in 1981 (both plots 3.0 to 2.0) and higher between the two 1982 dates (2.0 to 1.1 and 2.0 to 1.0).

3.4.2 Biodegradation (Alkane to Isoprenoid Ratio)

Biodegradation processes are evident from a comparison of the 1981 and 1982 ratios (Table 3.5). In particular, plots CE and D(B)C show a progressive change through time, whereas CC, MC, ME, D(B)E and the two D(E) plots show a less regular pattern but, nevertheless, have ratios on 29 August, 1982, that are all significantly lower than the post-test and +8 day values. The analytical results from the two D(B) plots are again influenced by the presence of a hydrocarbon solvent in the dispersant that was used on these plots.

3.5 DISCUSSION

The visual changes of the intertidal oiled plots are very evident. Figures 3.4 and 3.5 illustrate the natural removal of oil from the 8 test plots on the south shore of Crude Oil Point. This south-facing beach (Fig. 2.1) is sheltered from Eclipse Sound but, nevertheless, the upper intertidal beach plots were substantially cleaned between early August 1981 and mid-August 1982. These test plots were only partially cleaned during 1981 (see field log sheets in Woodward-Clyde Consultants, 1981). A similar visual change is evident on the countermeasure and control plots on the east-facing beach at Crude Oil Point (Fig. 3.6) over the same one-year time period.

Table 3.4 Geochemical Analyses Results:
Evaporative Weathering Ratio (SHWR)

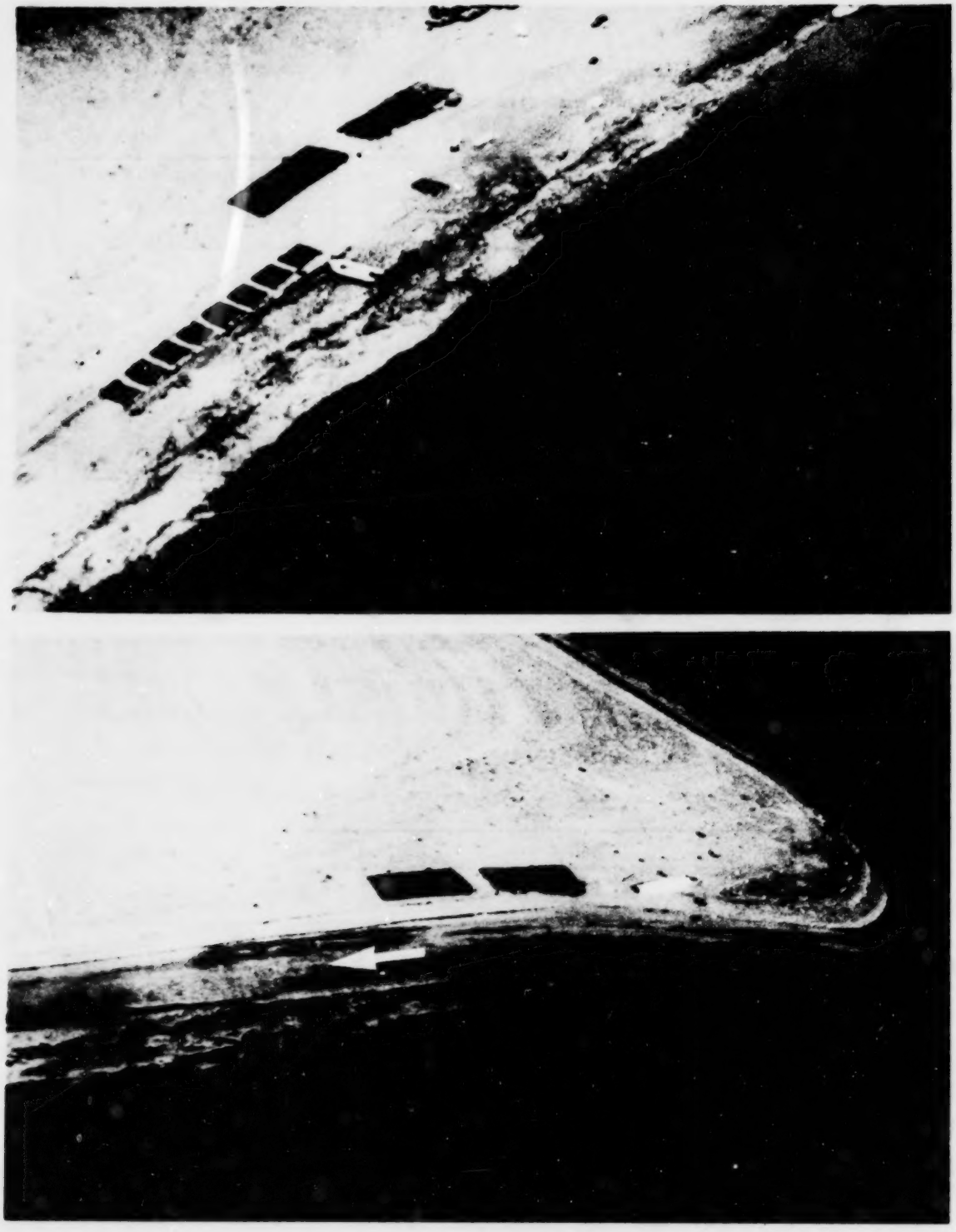
CODE	1981			1982	
	Post-Test	+8 Days	+40/41 Days	Aug 8	Aug 29
CC	3.0	2.6	1.6	1.3	1.1
CE	3.0	2.3	1.4	1.1	1.0
MC	3.0	1.8	2.0	1.9	1.1
ME	3.0	2.1	2.0	12.1*	1.0
D(E)C	2.3	1.8	1.9	2.4	1.1
D(E)E	1.9	1.9	-	2.6	1.4
D(B)C	7.0	1.4	2.6	1.5	1.8
D(B)E	20.9	3.3	1.2	2.7	1.8

*suspect value due to possible contamination of sample

Table 3.5 Geochemical Analyses Results:
Biodegradation (Alkane to Isoprenoid Ratio)

CODE	1981			1982	
	Post-Test	+8 Days	+40/41 Days	Aug 8	Aug 29
CC	2.1	2.6	1.6	2.2	1.6
CE	2.7	2.6	2.7	1.6	1.5
MC	2.1	2.1	2.5	1.9	1.7
ME	2.7	4.0	2.1	4.7*	1.1
D(E)C	3.2	4.1	2.6	3.2	1.2
D(E)E	3.2	2.8	-	3.0	2.2
D(B)C	3.8	2.9	2.7	1.2	0.7
D(B)E	5.3	4.5	1.2	2.2	2.2

*suspect value due to possible contamination of sample



(a)

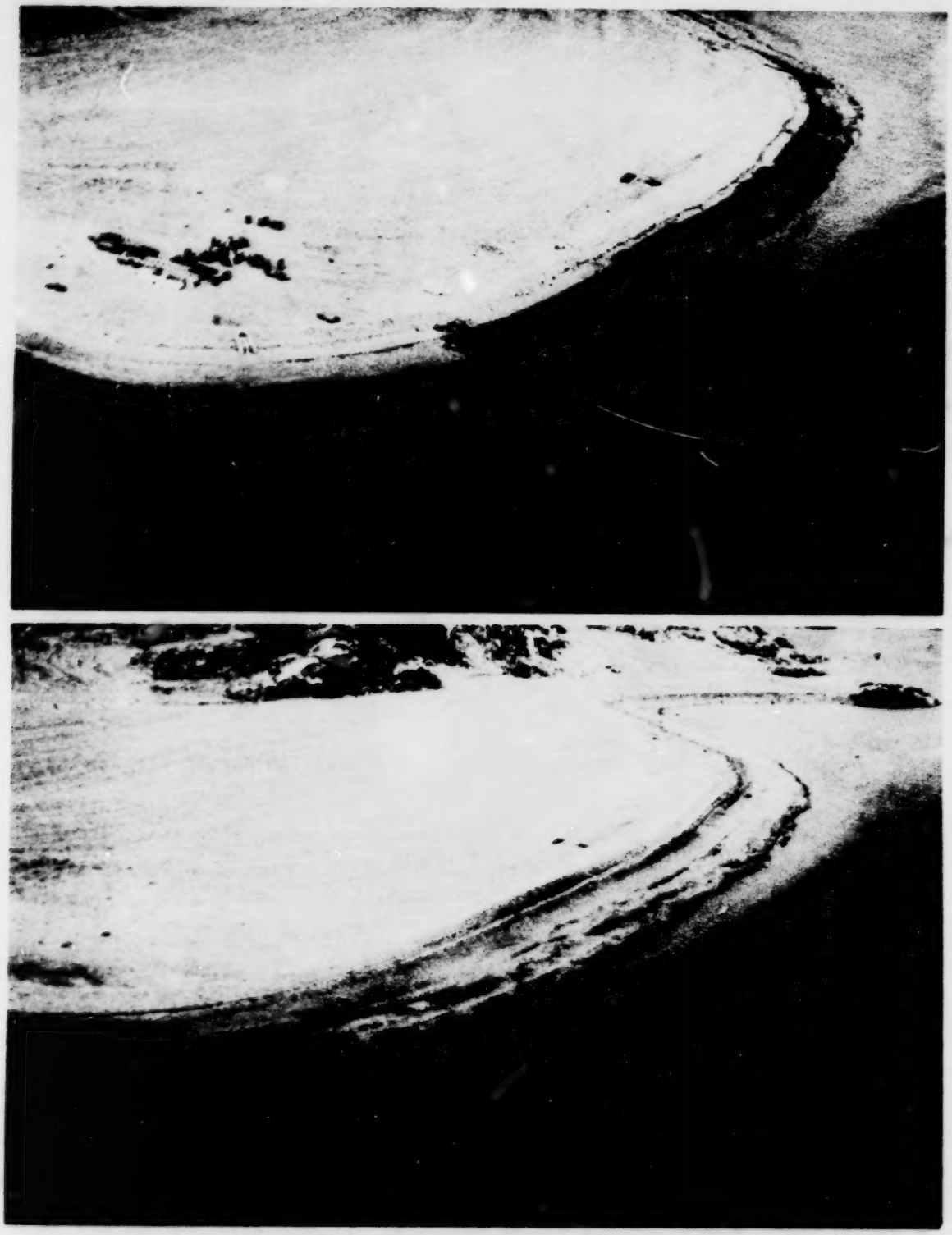
(b)

Figure 3.4 (a) Eight test plots on the south shore of Crude Oil Point, 4 August 1981.

(b) Site of test plots on the south shore of Crude Oil Point, 14 August 1982 (arrow locates Fig. 3.5)

Figure 3.5 Ground view of test plots area, 10 August 1982.

Ground observations on the countermeasures plots show that, although the plots themselves were largly free of oil, a layer of oiled sediments was present in August 1982 on the upper one-quarter of the MC and CC plots (Fig. 3.7a). To the south, on plots ME and CE a similar layer of oiled sediments was present at a slightly higher elevation, above the plots at the Highest High-Water Level (Fig. 3.7b). It is significant to note that no other oiled sediments were observed in the upper intertidal zone on this beach. The assumption can be made, therefore, that this layer of oiled sediments is directly associated with the mixing and control plots. The oiled sediments on the plots have been reworked and moved up the beach by normal wave processes. Profiles 40 and 60, which cross the ME, CE and CC plots, show accretion on the upper beach between late August 1981 and August 1982.



(a)

(b)

Figure 3.6 (a) Aerial view of countermeasure and control plots at Crude Oil Point, 8 August 1981.

(b) Aerial view of countermeasure and control plots at Crude Oil Point, 14 August 1982.

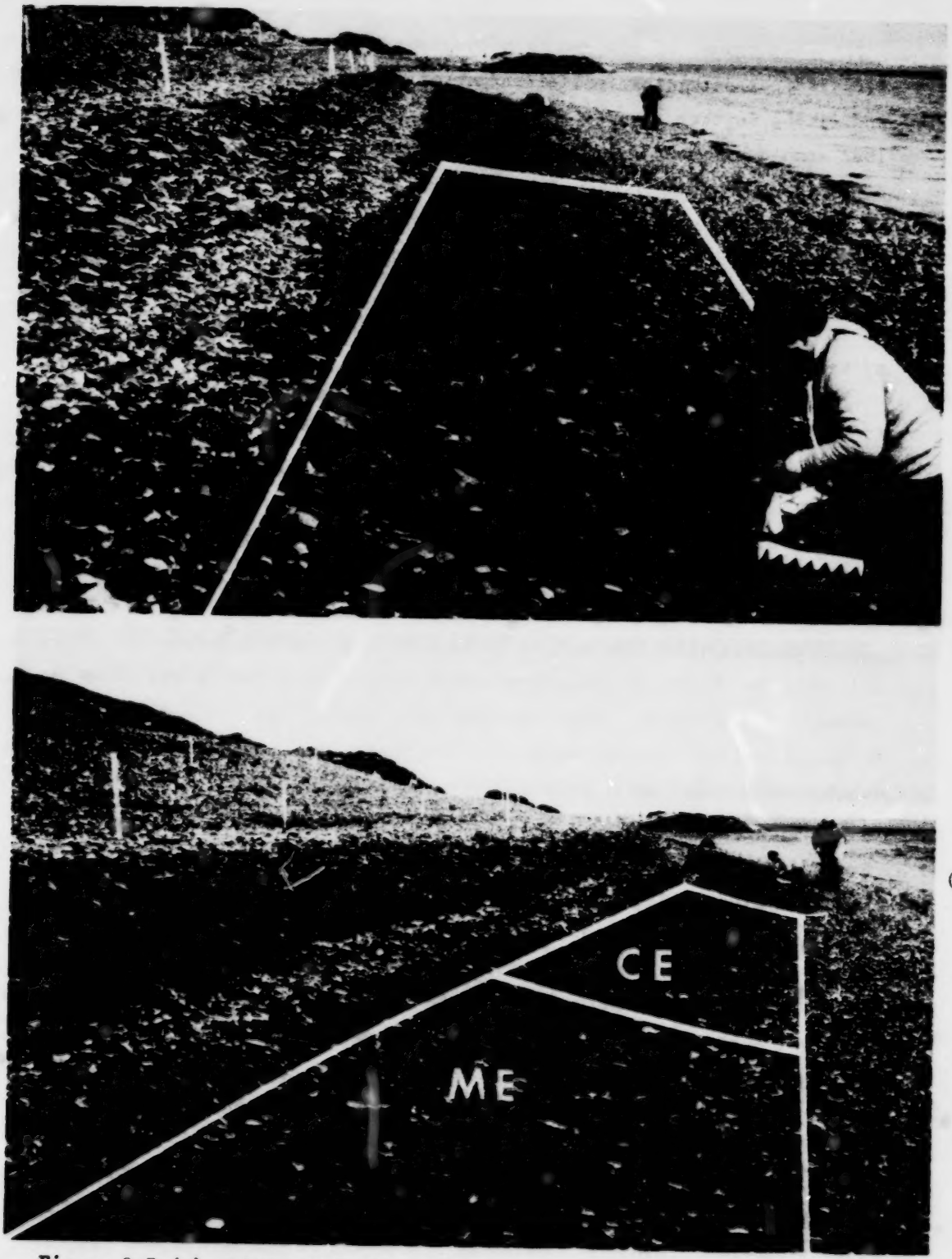


Figure 3.7 (a) View of MC plot, outlined by solid line, 10 August 1982. Note oiled sediments in upper plot.

(b) View of ME and CE plots, 10 August 1982. Note oiled sediments above plots.

A summary of the total hydrocarbon content of all samples (Table 3.6) indicates (i) the initial reduction of surface oil content during 1981 and (ii) a further reduction between the last 1981 sample set and the first 1982 sample set. The mean subsurface data show (iii) an initial increase of oil content immediately following the tests, and (iv) a major reduction in values before the last 1981 sample set with no significant changes in the 1982 results. The most important fact from the total hydrocarbon analyses is that relatively little oil was left on the plots during 1982. On only one plot (MC subsurface) did the oil-in-sediment value exceed 500 mg/kg.

The primary trends that can be deduced from the last data set of 1982 are that (a) there remains more oil on the control and mixing plots than on three of the four dispersant plots, and (b) there is less oil on the D(B) plots than on the D(E) plots. In addition, subsurface values are higher than surface values on three of the eight plots (CC, MC, and ME).

Although the dispersants drove oil into the subsurface sediments on all but the D(E)E plots, wave action was effective in reworking these subsurface sediments. This was not the case in the MC plot where the mixing resulted in contamination of subsurface sediments which were subsequently only partially cleaned by wave action.

The solidifier was still present on the plots in a form similar to that which was observed in late August 1981. No samples were taken of the solidifier plots. The solidifier was particularly evident on the SE plot where approximately 25 percent of the plot contained solidified sediments. The gelled sediments were in a single large "mat" at the southern end of the plot, where the polymer was mixed with a slow cross-link agent. On the SC plot only 10-15 percent of the plot contained solidified sediments; these were again concentrated at the southern end of the plot.

The beach profile surveys indicate a pattern of localized erosion and accretion. The data show clearly the accretion on the upper beach of oiled sediments eroded from plots ME, CE and CC. The changes in elevation

Table 3.6 Summary of Means of Samples Collected from All 1981 Countermeasures Control and Experimental Plots

	1981				1982	
	Pre-Test	Post-Test	+8 Days	+40/41 Days	Aug 8 Aug 10	Aug 29 Sept 02
t-h surface (mg/kg)	15,835	19,226	8,195	3,202	124	160
subsurface (mg/kg)	1,240	4,054	3,017	302	785	445
SHWR+	2.3*	2.7	2.1	1.8	1.5	1.1
ALK/ISO+	2.5*	2.6	3.0	2.3	2.4	1.6

* aged crude oil

+ not including D(B) data

on the beach have been up to 25 cm in places, indicating that wave activity on this beach during the open-water season was sufficient to rework the contaminated surface and subsurface sediments.

The summarized geochemical data (Table 3.6) indicate that evaporative weathering has been a significant degradation process, with a reduction of the mean ratio from 2.3 to 1.1 by the end of August 1982. On the control plots, the greatest change occurred during 1981, whereas on the mixed plots, there appears to have been as large a change in 1982 as was detected in 1981. The ALK/ISO results indicate a significant level of biodegradation on all plots, with the largest changes having occurred between the two 1982 sample periods.

The primary conclusions from the 1982 results are that the oiled plots have been cleaned, for the most part, as a result of the combination of countermeasures and of natural cleaning. The control plots had oil-in-sediment values of 500 mg/kg or less by the end of the second open-water season. The D(B) plots had the lowest hydrocarbon volumes, and these were achieved by the end of the first open-water season.

3.6 SUMMARY

An evaluation of the observations and data gathered over a two-year period indicates a number of significant points related to both the persistence of the oil that was laid down and the countermeasures that were used. These are the major findings to date:

- Relatively little oil remains on any of the experimental or control plots. By September 1982, only the mixed crude plot had a total hydrocarbon value greater than 500 mg/kg (i.e., 0.05 percent oil-in-sediment by weight).

- Visual observations show (a) a similar high rate of natural cleaning on the more sheltered (therefore lower energy) test plots on the south shore of Crude Oil Point, and (b) the presence of oil above both sets of mixed (MC and ME) and control (CC and CE) plots. It is significant that no such band of oiled sediments was present above the dispersant or solidifier plots.

- More oil remains on the control and mixing plots than on 3 of the 4 dispersant plots, and with the exception of plot CE, subsurface total hydrocarbon values are greater than surface values.

- The "cleanest" plots were those on which the BP dispersant was used; even though they are the most exposed plots, in terms of wave-energy levels, the fact that total hydrocarbon levels were low by day +8 suggests that dispersant effectiveness is the more significant parameter, rather than wave action.

- Sediment redistribution by wave action during the two open-water seasons resulted in beach profile changes in the order of 5 to 20 cm in most sections; this was sufficient in most cases to re-work the oiled sediments and to promote self cleaning. On the mixing and control plots, wave action resulted in a movement of oiled sediments up the beach-face slope and accretion in the area between the Mean and Higher High-Water Levels.

- The diagnostic geochemical ratios indicate that (i) significant evaporative weathering occurred between the last data set of 1981 and the September 1982 data set, and (ii) changes related to biodegradation were not uniform, but, in all cases, by the end of August 1982, biodegradation can be seen to have been an important weathering process.

- The solidified oil was still present on both plots where the gelling agent was applied, with a surface cover up to 25 percent. The sections where the fast cross-link agent were used did not appear to have any solidified sediments.

- At the scale and the loading volumes at which the countermeasures were tested, (1) the use of dispersants resulted in lower total hydrocarbon values at both initial (one week) and long-term (two year) intervals; (2) mixing appears to have delayed natural cleaning to some degree, but (3) after two open-water seasons, all beach plots were virtually clean either due to natural or man-induced processes; the only significant section of beach with remaining oil is a narrow band of contaminated sediments above the mixed and control plots.

4.1 INTRODUCTION

A series of experiments were conducted during 1982 on the southwest shore of "Z-Lagoon" in Bay 106 (Fig. 2.1). This site was selected for countermeasures tests as it is a low wave-energy environment with a maximum fetch in the order of 1500 m. Results obtained from the 1981 countermeasures experiments indicated that natural degradation associated with wave activity at Crude Oil Point was as effective as the selected techniques over a 40-day period. It was decided, therefore, to repeat the dispersant tests in a more sheltered location than Crude Oil Point. Bay 106 was selected as the site for the tests as this section of beach was the only suitable stretch of shore in "Z-Lagoon" that was sufficiently long and that was not dominated by cobble-sized sediments.

The experimental design involved testing of the same two dispersants that were used in 1981 on both aged crude oil and water-in-oil emulsion plots in the intertidal zone. In addition, control plots were laid down to provide a set of reference data. Backshore plots, above the normal high-water mark, were laid down for both oil types and were mixed using a rototiller. During the course of the experiment, it was decided to flush one half of the water-in-oil emulsion, intertidal control plot with a low-pressure hose. All of the control and experimental plots were sampled following the application of the oil and subsequently at intervals of 7 days and either 31 or 33 days. In addition, the experimental plots were sampled on the day following the experiment. The methodology used throughout this phase of the project followed closely that which was used in the 1981 tests in order to provide comparative results.

The mixing was conducted above the intertidal zone in order to determine whether or not this action would promote or delay degradation of oil stranded during storm surge events. On the intertidal plots, oil was redistributed farther up the beach from the area that was initially oiled, and this larger area rather than the oil plot alone was treated with dispersant and subsequently sampled.

4.2 EXPERIMENTAL DESIGN

4.2.1 Oil-Water Emulsification System

Preparation of the water-in-oil emulsion from the aged Lago Medio crude was carried out in the field (Fig. 4.1) following the procedures described and illustrated by Owens et al., (1982a).

4.2.2 Oil-Application Technique

The oil application system developed for the 1980 and 1981 studies was used in the manner described by Owens et al., (1982a). The only difference in the system was that the ATV was pushed, rather than driven, to provide a more even distribution of oil on the plot (Fig. 4.2). In addition, four of the six plots were oiled without the use of the pump as this was found to be too forceful a method and resulted in unacceptable displacement of the surface sediments (see Fig. 4.18). As in previous oilings, several passes were required to discharge the oil.

Figure 4.1 Field preparation of water-in-oil emulsion, 12 August 1982.

A trench was dug at the base of each plot to collect oil that ran downslope. The trench was lined with polyethylene, and where possible, an estimate was made of the volume of oil or emulsion that was collected from each trench (Fig. 4.3).

4.2.3 Oil Spill Contingency Measures

The oil spilled on the plots was controlled by a variety of methods in order to prevent contamination of adjacent sections of shore. Prior to oiling of the plots, plastic drip sheets were installed at the end of each plot to collect oil that would drip from the distribution pipe and a lined trench was dug along the base of each plot to collect oil that would run off the plots (Figs. 4.3 and 4.4a).

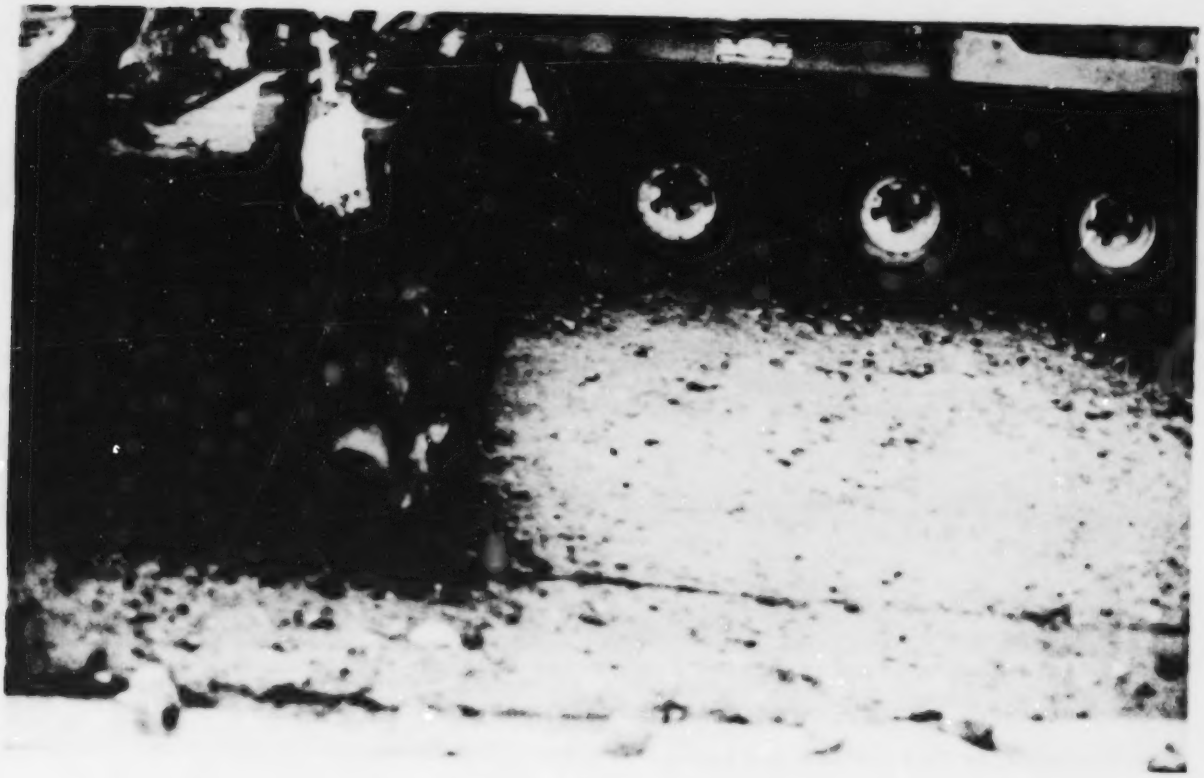


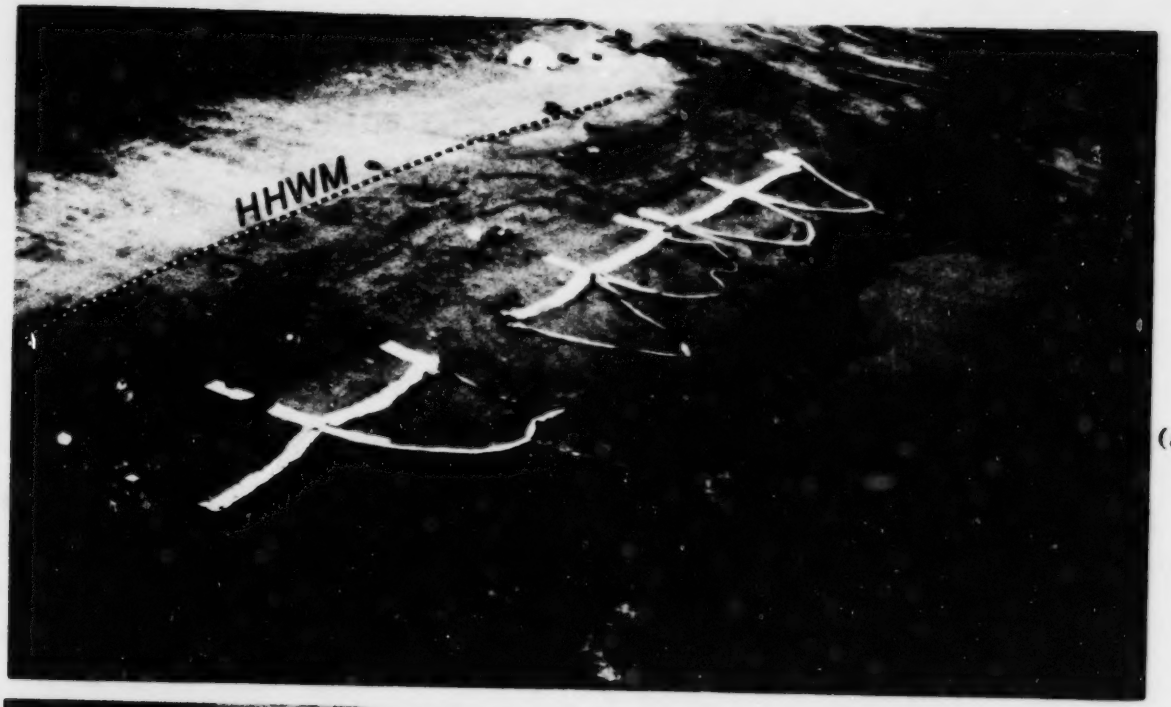
Figure 4.2 Oiling of plot ICC, 14:35, 12 August 1982.

Figure 4.3 Removal of oil from trench following application.

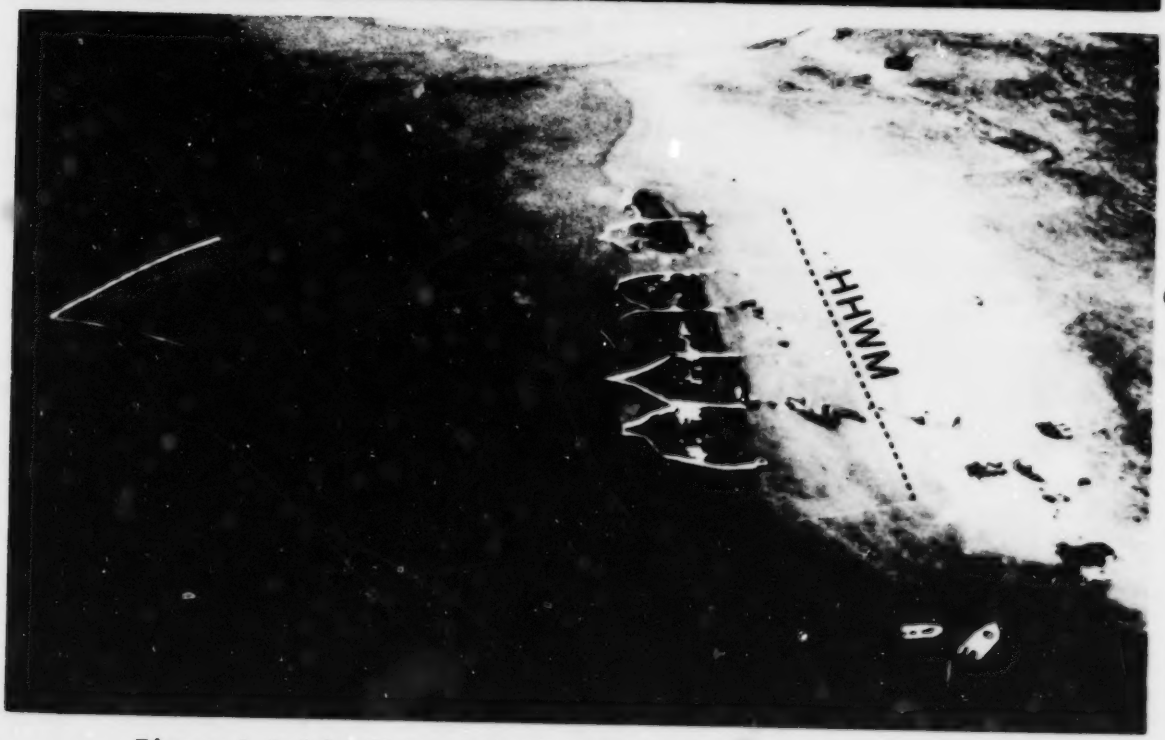
Booms were installed on the seaward margins of the plots to collect oil that would be lifted off the beach surface by the rising tide and carried seaward. The oil from the trenches and from the water surface within the boom was collected using cans, sorbent rolls and sorbent pads and was then burnt in barrels. An additional length of boom was moored in the nearshore adjacent to the beach site (Fig. 4.4b) as a reserve. This nearshore boom was located so that it remained afloat at low tide.

4.2.4 Experimental Layout and Schedule

Six plots were established on the upper intertidal zone of the beach. Each plot was 2-m wide and approximately 10-m long. Two plots were laid down above the normal high-water mark to replicate oil that might be stranded above the normal limit of wave action during a period of high water levels (storm surges). The relative location of the plots is shown in Figure 4.5 (see also Fig. 4.4b), and the plot identification codes are given in Table 4.1



(a)



(b)

Figure 4.4 (a) Plots prior to application of oil, 14:30, 12 August 1982 (HHWM - Highest High-Water Mark).

(b) Plots immediately following application of oil, 16:40 12 August 1982. Note rise in water level compared to Figure 4.4a.

Each of the crude oil plots was oiled with one barrel of the aged crude oil, and the emulsion plots were oiled with two barrels of the water-in-oil emulsion. The intertidal plots were oiled on 12th August. On the following day, when the countermeasures were tested, the oil coverage extended from the plots up to the high-water swash mark. The dimensions of the intertidal plots on 13th August are shown on Figure 4.6.

One modification was made to the original design during the experiment; this involved using the eastern half of the emulsion control plot for a test of low-pressure flushing (plot ICE-E).

The two backshore plots were laid down on 13th August and the two central halves of each plot were mixed using a rototiller on 15th August, 52 hours after the oil had been laid down. The two outside halves were left for control sampling. The suffices "c" and "e" in Table 4.1 refer to "centre" and "end" respectively. Additional backshore plots were laid down on 1982 August by the Norwegian team: the plots and the associated studies are described elsewhere by Eimhjellen et al., (1983).

Table 4.1 Plot Identification Codes for 1982 Experiments in Bay 106.

ICC	intertidal crude	- control oil
ICE-E	intertidal emulsion	- flushed by low-pressure dispersion
ICE-W	intertidal emulsion	- control
ICE(B)C	intertidal crude	- dispersed with BP 1100X
ICE(B)E	intertidal emulsion	- dispersed with BP 1100X
ID(E)C	intertidal crude	- dispersed with Corexit 7664
ID(E)E	intertidal emulsion	- dispersed with Corexit 7664
IMC-c	backshore crude	- mixed by rototiller
IMC-e	backshore crude	- control
IME-c	backshore emulsion	- mixed by rototiller
IME-e	backshore emulsion	- control

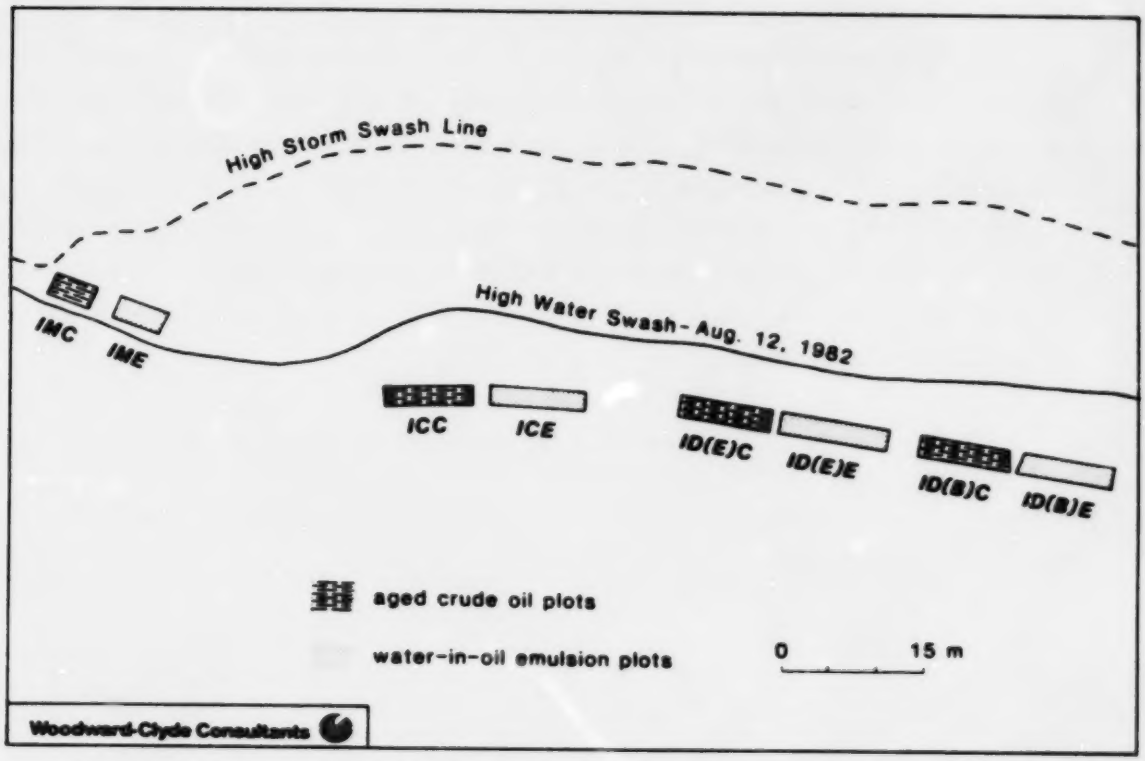


Figure 4.5 Location of 1982 countermeasure and control plots as initially laid down. The test beach is located on Figure 2.1 and the plot identification codes are given in Table 4.1.

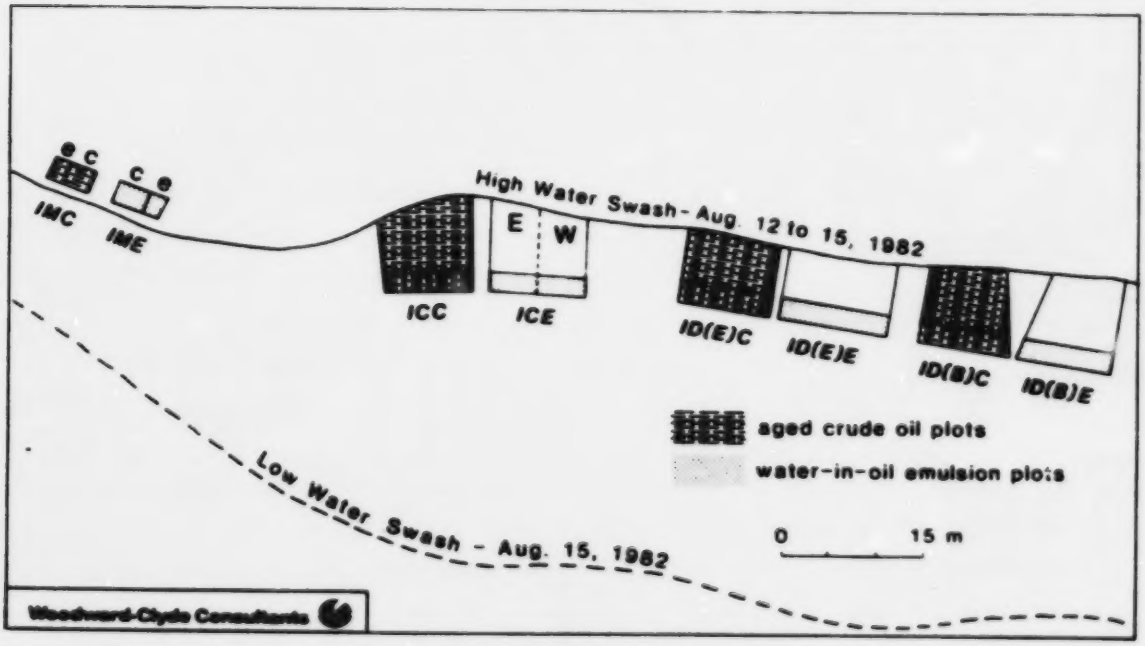


Figure 4.6 Plot dimensions on 13 August 1982, 24 hours (2 low-tidal cycles) following oiling: note that the two mixing plots are above the normal high tide swash.

The schedule of events for each plot is described in the field log sheets that are given in the Interim Field Report (Section 4.4: Woodward-Clyde Consultants, 1982). A summary of the schedule of activities is given in Table 4.2. Beach profiles were surveyed across the plots and the location of the profile lines is presented in Figure 4.7. Subsequent to 15th August, samples were collected on 20th August and 15th September, 1982, from the intertidal plots, and on 22nd August and 15th September, from the backshore plots.

Table 4.2 Schedule of Activities for the Bay 106 Experiments in 1982.

(a) Intertidal Plots	
12 August (14:30 - 15:20)	• plots oiled
13 August	• plots sampled (pre-test)
(16:50 - 18:10)	• applied dispersants and low-pressure flushing
14 August	• plots sampled (day +1)
20 August	• plots sampled (day +7)
15 September	• plots sampled (day +33)
(b) Backshore Plots	
13 August (11:35 - 11:50)	• plots oiled
14 August	• plots sampled (pre-test)
15 August (14:50 - 15:05)	• plots mixed
	• plots sampled (day 0)
22 August	• plots sampled (day +7)
15 September	• plots sampled (day +31)

4.2.5 Data Collection

(a) Beach Profiles:

One set of beach profiles was surveyed on 15th August 1982, from the low-water swash line across the intertidal zone to beyond the highest storm-swash line. The profiles are presented in Appendix A and the location of the plots and the high-water mark is shown for each of the intertidal profiles.

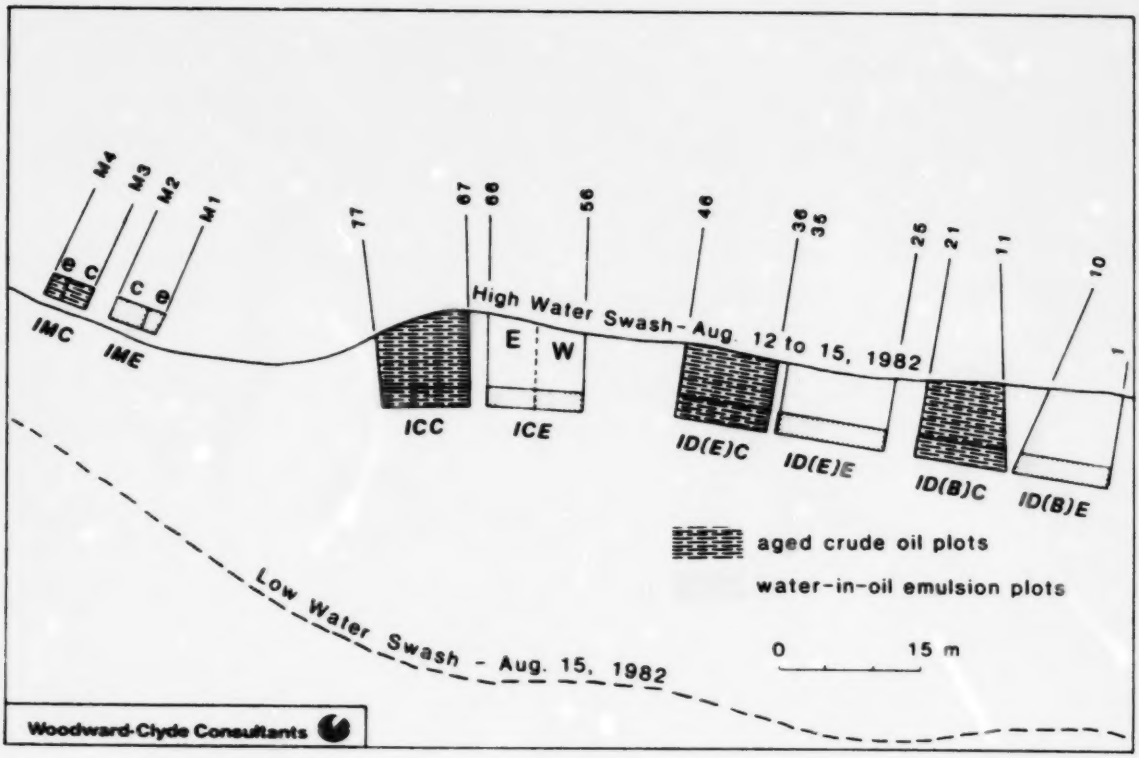


Figure 4.7 Location of surveyed beach profile lines with reference to the experimental plots.

(b) Intertidal Samples:

Samples were collected for total hydrocarbon content of the beach sediments and for GC/MS analysis at prescribed intervals. The original sampling design for the intertidal plots was based on sampling of the oiled plots alone. Within 24 hours of the application of the oil, however, it was evident that it would be necessary to also sample the beach for total hydrocarbon content between the plots and the highest swash level of 12-13 August. Each extended plot was subdivided into 6 rows that were parallel to the plot (Fig. 4.8a), and one sample was obtained by compositing 4 sub-samples from each row. The basic total hydrocarbon sample pattern that was developed is as follows:

12 August	• post oiling (same day)
13 August	• post oiling/pre-test (24 hours after oiling) rows 2, 4, 6

14 August	• post-test (24 hours after test) rows 2, 3, 4, 6
20 August	• post-test (7 days) rows 1, 2, 3, 4, 6
15 September	• post-test (33 days) rows 1, 2, 3, 4, 6

The location of each row with respect to important high-water swash levels on the beach is given in Figure 4.8a.

The data from this sample programme are presented in Appendix B. In this appendix, the relationship between the row numbers and the sample location description is:

1 - highest
2 - top
3 - upper
4 - middle
6 - plot

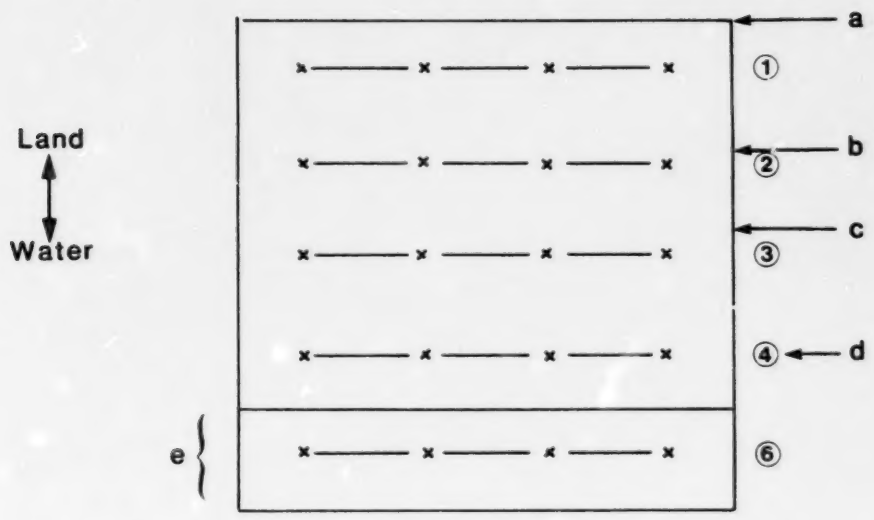
Samples for GC/MS analyses were collected from the barrels, prior to application of the oil, at 24 hours, 7 days and 33 days after the test. These samples were obtained as a composite of four sub-samples on row 2 of each plot. The data from these analyses are given in Appendix C.

(c) Backshore Samples:

The mixing plots (IMC and IME) were subdivided into mixed (c) and unmixed or control (e) sections (Fig. 4.8b). In addition, because of a significant across-shore difference in the sediment character, the plots were divided into backbeach and berm sections; these two sections were sampled separately for total hydrocarbon content. The plots were sampled for total hydrocarbon and for GC/MS on the following schedule:

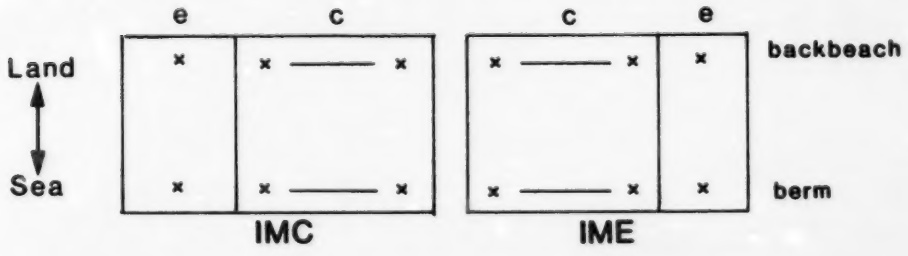
14 August	• post oiling/pre-test (24 hours after oiling)
15 August	• post-test (same day)
22 August	• post-test (7 days)
15 September	• post-test (31 days)

a. Intertidal plots (not to scale)



a. highest high-water swash prior to 20 Aug. 1982
b. high-water swash 12 August, 1982
c. high-water swash 13 August, 1982
d. approx. 2m landward of oiled plot
e. oiled plots

b. Backshore plots



e. = control
c. = mixed section

Figure 4.8 Sketches of sampling patterns used on experimental and control plots.

4.3 COUNTERMEASURES TECHNIQUES

4.3.1 Introduction

The choice of techniques was based on the desire to continue the types of experiments that were conducted in 1981, but in an environment with lower wave-energy levels at the shoreline. The primary technique for the intertidal plots involved the two chemical surfactants BP 1100X and Corexit 7664. The mixing experiments were conducted on this occasion in the area above the normal high-water mark, rather than in the intertidal zone, to assess the value of the technique as a method of promoting the natural degradation of oil stranded during periods of storm-wave activity or storm surges.

An additional experiment was conducted to determine the relative efficiency of flushing with Corexit 7644 or with sea water alone. The same pump and hose system were used in both experiments. Further details on the techniques are presented in the 1981 Working Report (Owens et al., 1982a).

4.3.2 BP Dispersant

The dispersant BP 1100X was applied from a hand sprayer (Fig. 4.9) on an incoming tide. The pressure of the spray unit is low, as the dispersant is designed to disperse oil into small particles with mixing processes that occur naturally on a beach. Approximately 10 litres of dispersant were applied to the two plots ID(B)C and ID(B)E (Fig. 4.7). The dispersant was then left to be flushed naturally by hydraulic processes.

4.3.3 Exxon Dispersant

The dispersant Corexit 7664 was applied to the plots using a Homelite pump, an eductor for addition of the chemical and a 2"-internal diameter fire hose (Fig. 4.10). Approximately 10 litres were applied to each plot, on a rising tide, in a dilution with sea water at an oil-to-dispersant ratio in the order of 4:1 by volume.

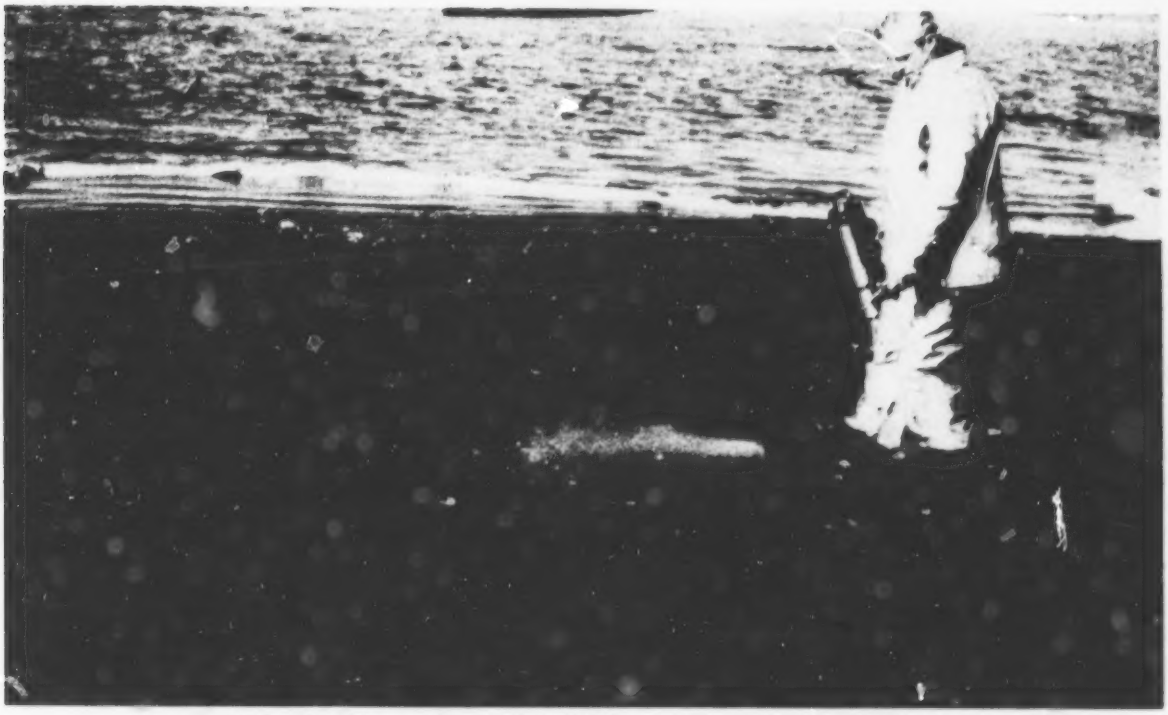


Figure 4.9 Application of BP 1100X to plot ID(B)E, 13 August 1982.

Figure 4.10 Application of Corexit 7664 to plot ID(E)E, 13 August 1982.

4.3.4 Low-Pressure Flushing

One half of the water-in-oil emulsion control plot (ICE-E in Fig. 4.6) was flushed with the same pump and hose system that was used to apply the Corexit dispersant. The plot was flushed for 5 minutes, on a rising tide beginning at the top of the plot and working seawards (Fig. 4.11).

4.3.5 Mixing

The surface sediments on the central sections of the two oiled backshore plots were turned over using a gasoline-powered rototiller (Fig. 4.12). The tynes mixed the sediments to a depth of 20 to 30 cm, and the plots were turned over both at right angles and parallel to the water line.

4.4 EXPERIMENTAL RESULTS

4.4.1 Introduction

The site chosen for the 1982 experiments is a very sheltered environment at the head of "Z-Lagoon" (Bay 106 in Fig. 2.1). The maximum fetch is in the order of 1500 m, and the shore is completely sheltered from waves generated during the open-water season in Eclipse Sound.

The intertidal zone varies between 50 and 75 m in width (Fig. 4.13) and the sediments have a mean size of 2.81 ϕ (0.14 mm: fine sand) (McLaren et al., 1981). The sediments are composed of:

clay	8%	weight by volume
silt	20	
sand	59	
gravel	13	

The fine-grained intertidal sediments (Fig. 4.14) have produced a flat, low-angle intertidal slope. The surface sediments are firmly packed when dry, but are frequently water-saturated when exposed by low tidal water levels. No berm has been formed on this beach; the profile is generally uniform and grades uniformly landward into the super-tidal zone (see profiles in Appendix A, Fig. A-3).

Figure 4.11 Low-pressure flushing on plot ICE-W, 13 August 1982.

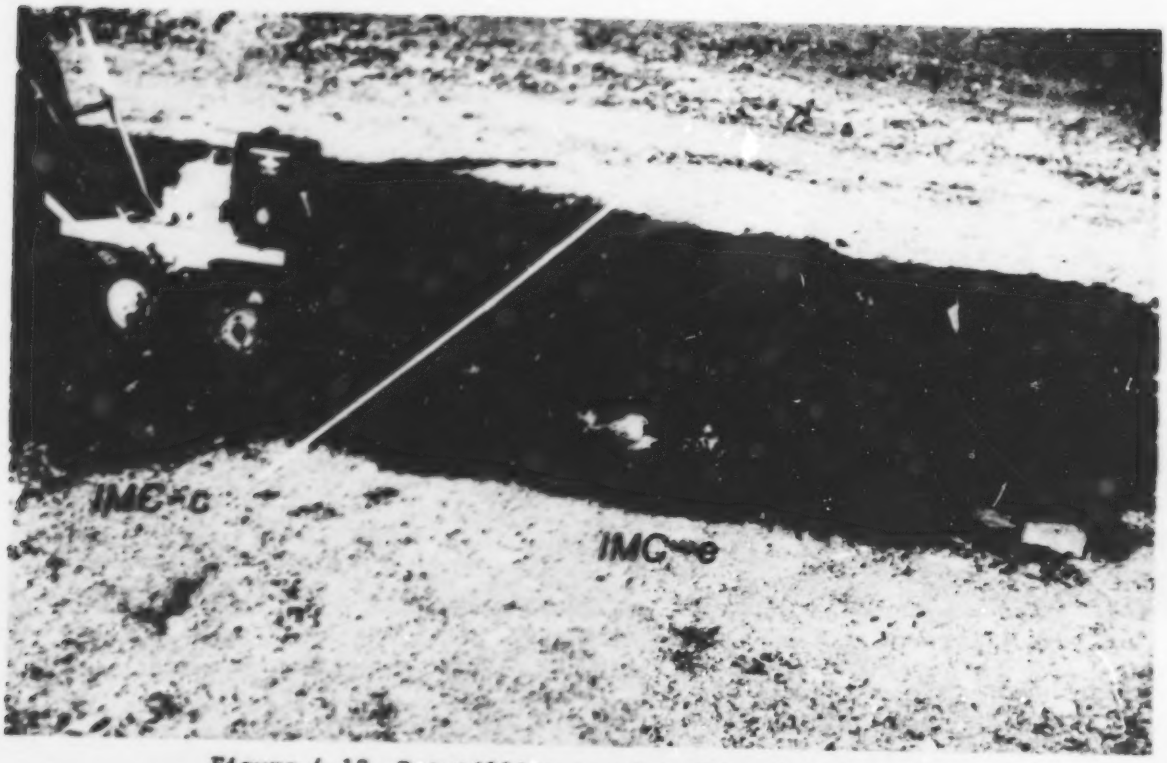
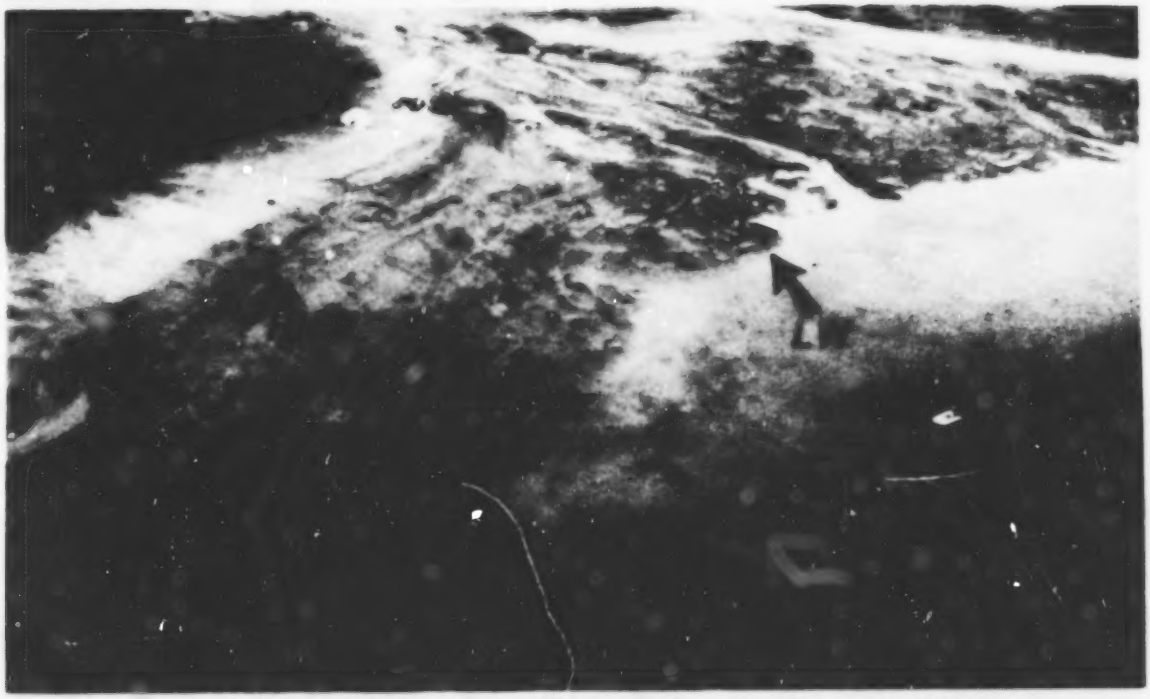


Figure 4.12 Rototilling on plot IMC, 15 August 1982.

(a)



(b)

Figure 4.13 (a) Aerial view at "Z-Lagoon". Single arrow indicates backshore plots, double arrows locate the intertidal plots in Bay 106, 14 August 1982.

(b) Bay 106 beach prior to experiments (10:15, 12 August 1982). HHW - Higher High Water; LW - Low Water.

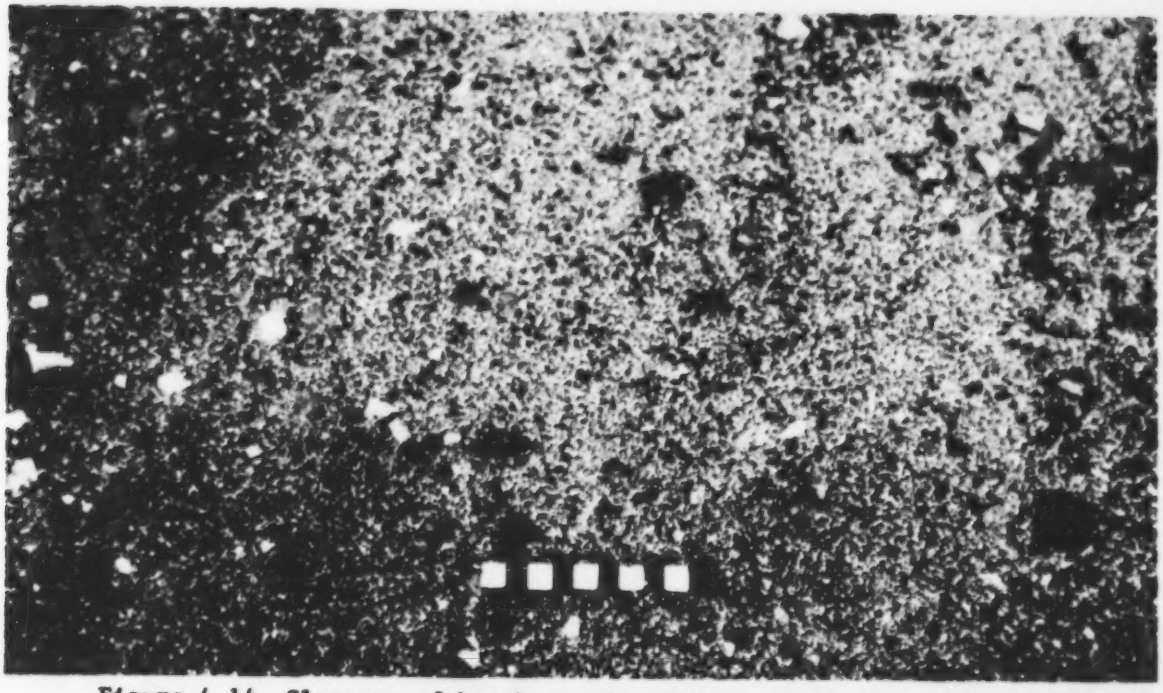
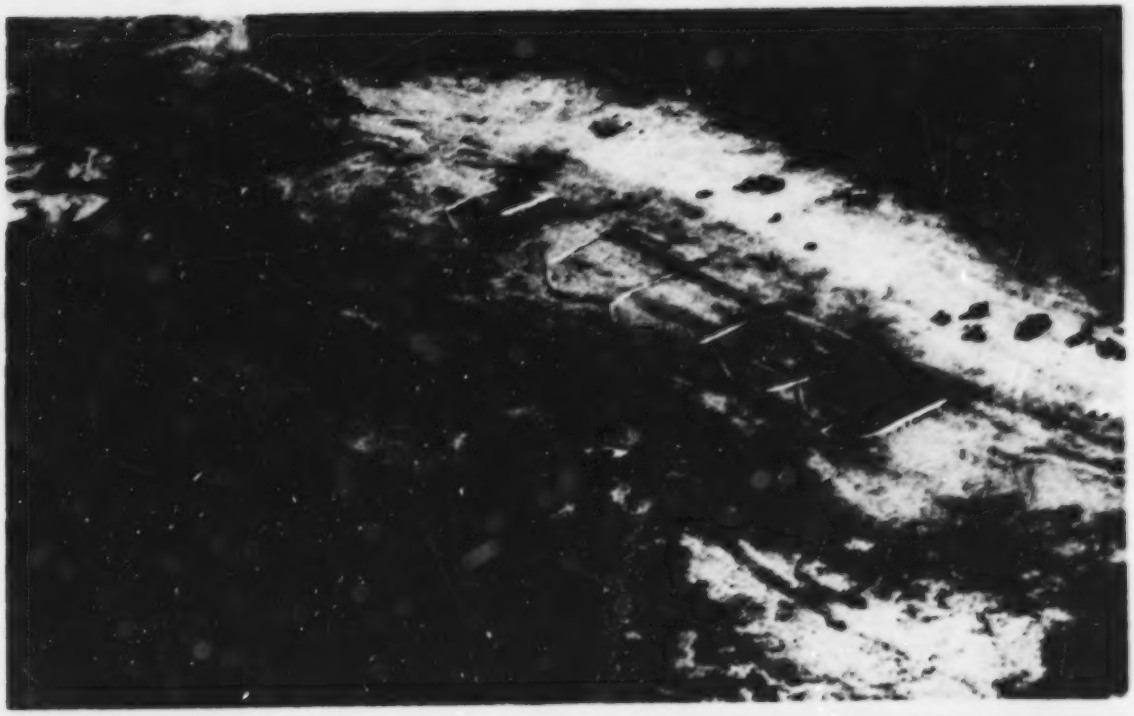


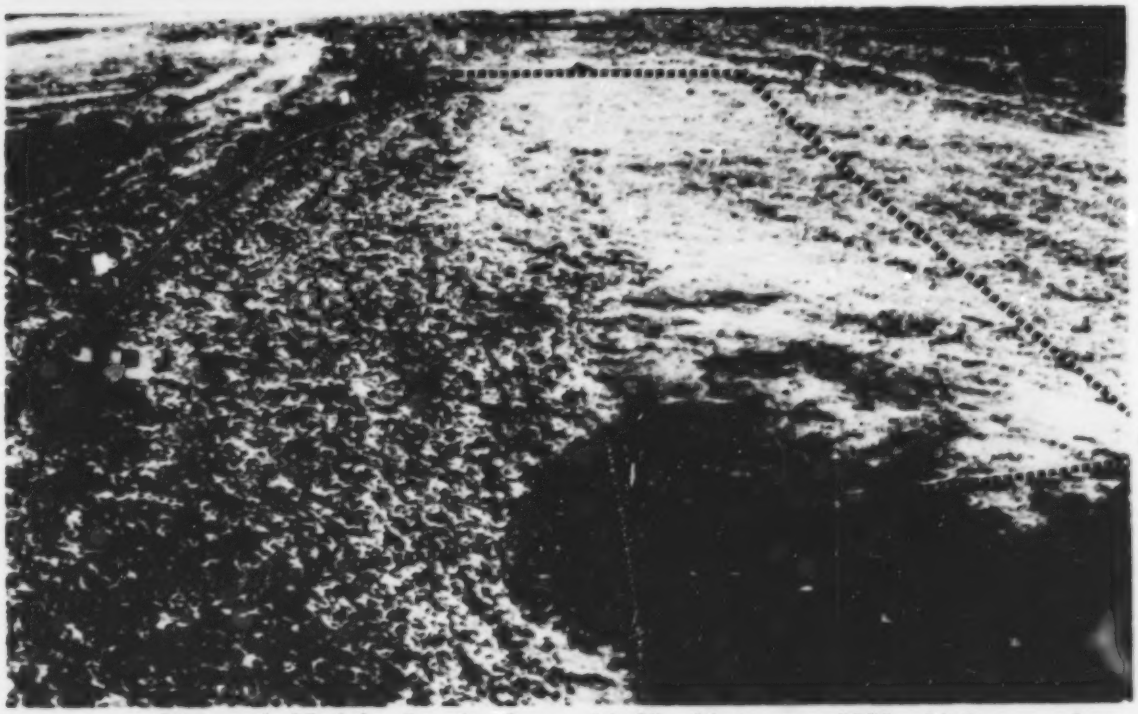
Figure 4.14 Close-up of beach on plot ID(B)E, 12 August 1982. Scale is graduated in cm.

At the eastern end of the study beach, a small protuberance (Fig. 4.15a) is characterized by coarse sand and granule sediments (Fig. 4.15b) that have a steep beach-face slope and a low storm berm (see profiles M1 to M4 in Fig. A-3, Appendix A). This site was selected for the super-tidal mixing experiments. The berm is characterized by predominantly gravel-sized material and is between 1- and 2-m wide with a pronounced backslope. At the landward base of the backslope, the sediments change to become firmly packed sands with a partial (25%) vegetation cover. This backbeach slopes up at a low angle and, from debris-line evidence, is only affected by waves during periods of storm-wave activity or during storm surges.

The predicted tidal curves from Cape Hatt for the initial study period (August 11 - August 25) are shown on Figure 4.16. These predicted tide heights and times coincide closely with field observations. For example, the predicted higher high tides between August 10 and 13 were 0.61, 0.62. 0.63 and 0.66 m; the surveyed corresponding high-water swash elevations were 0.61 and, 0.60, 0.68 and 0.62 m respectively. The minimum and maximum predicted ranges of the mixed semi-diurnal tides between August 11th and September 15th, 1982, were 0.51 and 2.07 m respectively.



(a)



(b)

Figure 4.15 (a) Beach plots, 14:20, 14 August 1982, 24 hours after intertidal experiments. Arrow locates two backshore IM plots.

(b) Area of backshore plots (dashed lines) prior to oiling, 13 August 1982.

The tidal water levels are important in the interpretation of the total hydrocarbon analysis results. The top of the intertidal plots were established at elevations that ranged between 0.4 and 0.5 m (note: all elevations are corrected to a mean water-level datum). The high-tide water levels on the day of the oiling (12 August) and on the subsequent 3 days ranged between 0.6 and 0.8 m above datum. The higher elevation is represented in Figure 4.8a (page 4-11) by line "b". The highest swash elevations between 15 and 20 August were in the area of 1.00 to 1.05 m, and these are represented in Figure 4.8a by the line "a".

Although these water-elevation differences are relatively small, on the day following the application, oil had spread from the initial 2-m wide plots to cover between 5 and 8 m of the upper beach from the top of the plot to the high-water swash lines (Figs. 4.5, 4.6 and 4.17), because of the low-angle slope of the intertidal beach at this site. The sampling programme that was developed during the experiment, therefore, reflects this increased size of the oiled areas.

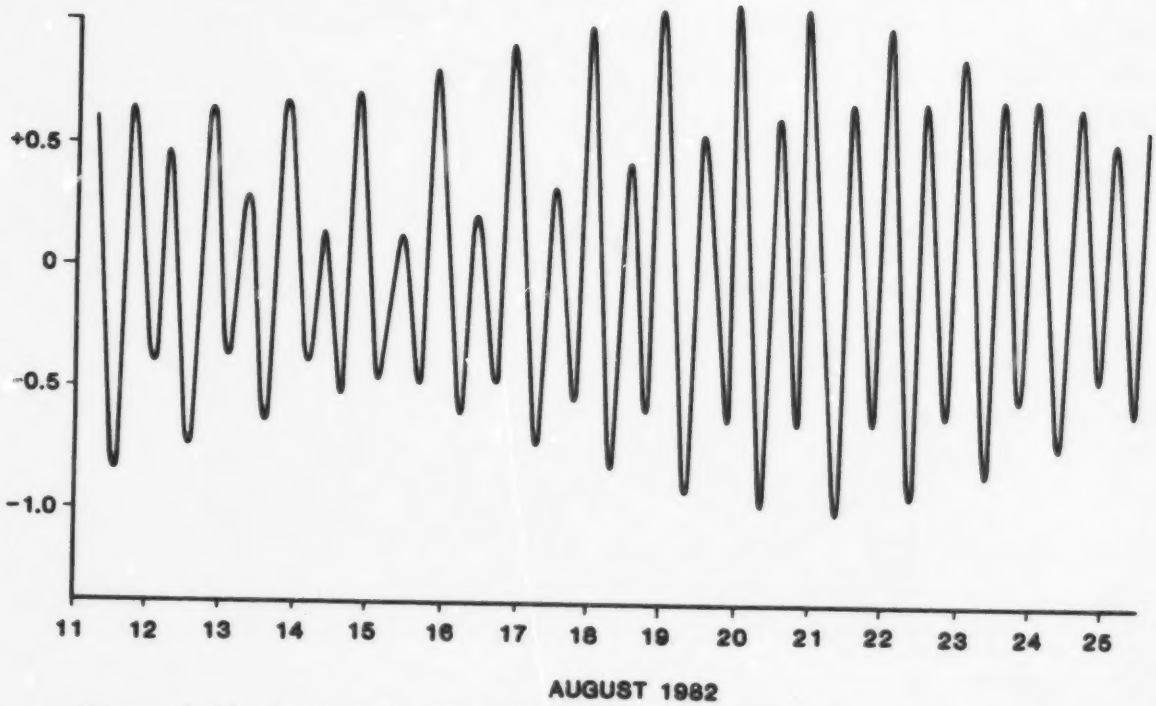
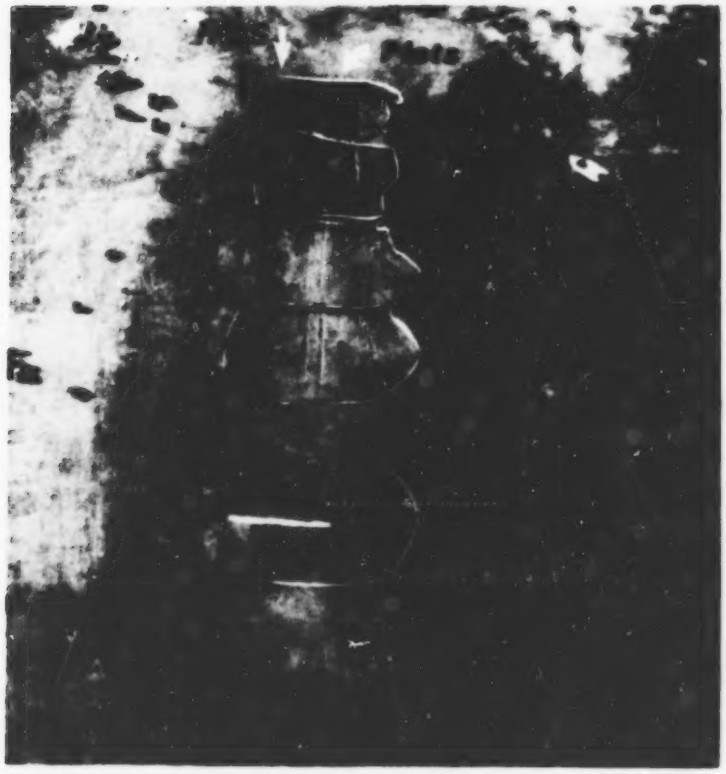


Figure 4.16 Predicted tidal curves for Cape Hatt (elevations in metres: 0 is the Mean Water Level).

(a)



(b)

Figure 4.17 (a) Intertidal plots immediately following application of oil, 16:40, 12 August 1982.

(b) Intertidal plots 48-hours after oiling, 24 hours after the tests, 14:20 14 August 1982. HWS - High Water Swash on 12 and 13 August.

4.4.2 Control Plots: ICC and ICE-W

The initial loading of oil on the control plots (Fig. 4.18) was similar to the values obtained from oil-in-sediment samples collected on the Bay 11 beach (Table 4.3). The total hydrocarbon value from the aged crude plot is lower than the values from the high-energy, Crude Oil Point control, and the low-energy aged crude plots. This reflects the sediment character of the different beaches. Both Bays 106 and 11 are characterized by low-angle slopes and fine-grained sediments, although Bay 11 has a surface pebble-cobble veneer in many sections. More oil is retained on the pebble-cobble beaches than on the fine-grained beaches. A similar pattern is evident in the values for the high-energy and Crude Oil Point emulsion plots, but the Bay 106 loading is considerably higher than that on the low-energy emulsion plot (Table 4.3).

Within twenty-four hours after oiling, the oil had been redistributed across the upper beach (Fig. 4.19) up to the vicinity of the swash line indicated in Figure 4.6. There was no cross-contamination between plots due to control measures that were taken to prevent this occurrence. This redistribution resulted in a significant lowering of total-hydrocarbon values on the plots, except ID(E)C and ID(B)E. At this sampling time the mean oil-in-sediment value from all of the crude plots was reduced from 9,400 to 2,220 mg/kg, and the mean value in the vicinity of the high-tide swash was increased to 13,963 mg/kg (Table 4.4). On the emulsion plots, the mean values were reduced from 7,310 to 5,115 mg/kg, and in the high-tide swash area, were 3,010 mg/kg. Thus more oil was lifted from the crude oil plots than the emulsion plots, with corresponding higher oil-in-sediment values on the upper sections of the crude plots.

Relatively little oil was deposited in the zone between the plots and the high-water swash, with only one composite sample (ID(B)C) having a value more than 700 mg/kg (Table 4.4).

Little oil penetrated into the subsurface sediments during the 24-hour period following application of the oil (Table 4.5). Only one plot exhibited significant subsurface oiling; ID(E)C, which had the only value greater than 500 mg/kg.

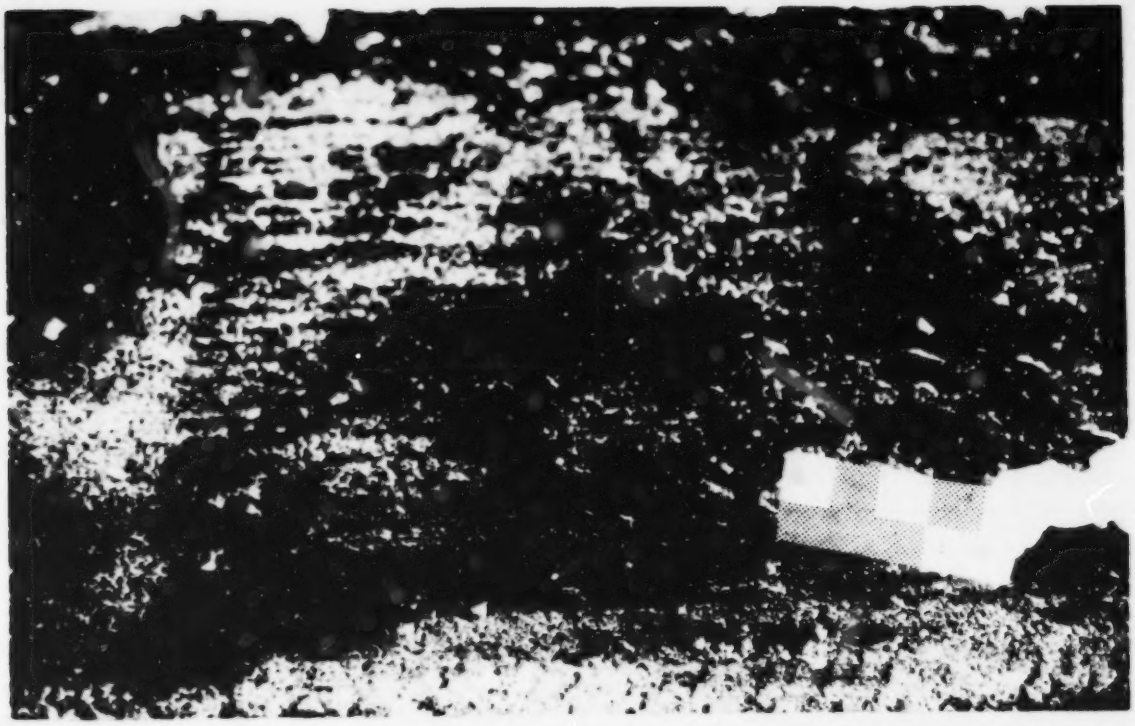
Table 4.3 Initial Loading Values from Control Plots

(a) Crude Plots		
High Energy (H1)	36,500	mg/kg
Crude Oil Point (all plots)	20,250	
Low Energy (L1)	17,100	
Bay 106 (all plots)	9,400	
Bay 11	mean 7,100	(max. 18,000)
(b) Emulsion Plots		
High Energy (H2)	13,700	mg/kg
Crude Oil Point (all plots)	15,000	
Low Energy (L2)	3,400	
Bay 106 (all plots)	7,300	

Over the 33-day sampling period on the control crude plot, the total volume of surface oil remaining was reduced progressively, due to a greater redistribution across the plot but also due to removal from the plot area (Table 4.4). The subsurface oil values remained low throughout (Table 4.5). On the emulsion plot, the surface oil was largely removed from the plot by the time of the last sample set, but high values occurred in the high-tide swash area (Table 4.4). This high value on row 2 is mirrored in the subsurface sample (Table 4.5).

The geochemical analyses (Table C.3 in Appendix C) indicate a considerable reduction in the SHWR from the barrel oil ratios to those obtained at 7 days following the tests (3.2 to 1.9 on ICC: 2.9 to 1.6 on ICE). This initial rapid evaporative weathering would be expected. The ratios changed relatively little between days 7 and 33.

Biodegradation, as indicated by the Alkane-Isoprenoid ratio (Table C.3), was not a factor in the weathering of the oil during the 1982 sample period; no significant changes in the ratios were identified.



(a)

(b)

Figure 4.18 (a) Plot ICC, west end, immediately following application of oil; 16:45, 12 August 1982. Scale is 25 cm in length.

(b) Plot ICC, east end, 16:45 12 August 1982.

Table 4.4 Total Hydrocarbon Results - Intertidal Surface Samples (mg/kg). Row numbers refer to locations shown on Figure 4.8a. Identification codes for the plots (columns) are defined in Table 4.1.

	ICC	ICE-E	ICE-W	ID(E)C	ID(E)E	ID(B)C	ID(B)E	
6	15,300	8,800	8,800	4,090	4,850	8,810	8,280	POST OILING 12 August
1	-	-	-	-	-	-	-	
2	11,000	1,730	1,730	21,200	2,080	9,690	5,220	PRE-TEST
3	-	-	-	-	-	-	-	13 August
4	160	270	270	70	690	2,860	540	(day 0)
6	1,460	6,330	6,330	4,360	1,680	840	7,340	
1	-	-	-	-	-	-	-	
2	-	11,000	1,600	12,800	2,160	20,400	40,900	POST
3	-	9,660	2,390	1,980	1,320	18,500	34,000	TEST
4	-	430	310	130	230	30	8,960	(+1 day)
6	-	24,000	5,910	420	1,520	8,300	20,200	

Table 4.4 (cont'd)

	ICC	ICE-E	ICE-W	ID(E)C	ID(E)E	ID(B)C	ID(B)E	
1	-	70	50	80	910	1,140	390	
2	6,860	1,170	230	8,770	15,200	27,900	29,100	POST TEST 22 August (+7 days)
3	620	33,600	1,040	930	2,180	10,500	6,340	
4	100	460	260	260	530	5,060	4,810	
6	5,240	15,900	4,630	120	1,510	2,760	11,800	

	ICC	ICE-E	ICE-W	ID(E)C	ID(E)E	ID(B)C	ID(B)E	
1	400	40	230	330	450	320	530	
2	200	1,370	8,210	5,530	1,520	12,300	6,870	POST TEST 15 September (+33 days)
3	650	15,100	530	270	380	1,730	1,810	
4	620	1,180	200	1,290	1,200	3,240	1,590	
6	2,130	11,900	830	30	130	170	690	

Table 4.5 Total Hydrocarbon Results - Intertidal Subsurface Samples (mg/kg). Row numbers refer to locations shown on Figure 4.8a. Identification codes for the plots (columns) are defined in Table 4.1.

	ICC	ICE-E	ICE-W	ID(E)C	ID(E)E	ID(B)C	ID(B)E	
6	-	-	-	-	-	-	-	POST OILING 12 August
1	-	-	-	-	-	-	-	
2	50	0	0	30	0	370	0	PRE-TEST
3	-	-	-	-	-	-	-	13 August
4	0	0	0	0	0	0	0	(day 0)
6	40	90	90	5,440	0	50	410	
1	-	-	-	-	-	-	-	
2	-	0	30	40	100	200	1,320	POST
3	-	90	50	0	30	40	30	TEST
4	-	0	0	0	0	7,130	60	(+1 day)
6	-	40	80	460	0	0	50	

Table 4.5 (cont'd)

	ICC	ICE-E	ICE-W	ID(E)C	ID(E)E	ID(B)C	ID(B)E	
1	0	0	0	0	0	0	0	
2	0	0	0	0	100	70	30	POST TEST
3	0	30	0	50	0	50	0	22 August
4	0	0	0	0	0	0	0	(+7 days)
6	0	30	0	0	0	0	0	
1	50	-	30	0	0	30	150	
2	50	180	5,720	1,270	0	2,300	7,910	POST TEST
3	420	180	0	2,530	200	2,230	360	15 September
4	0	90	0	0	30	3,240	4,340	(+33 days)
6	0	270	0	0	0	210	260	

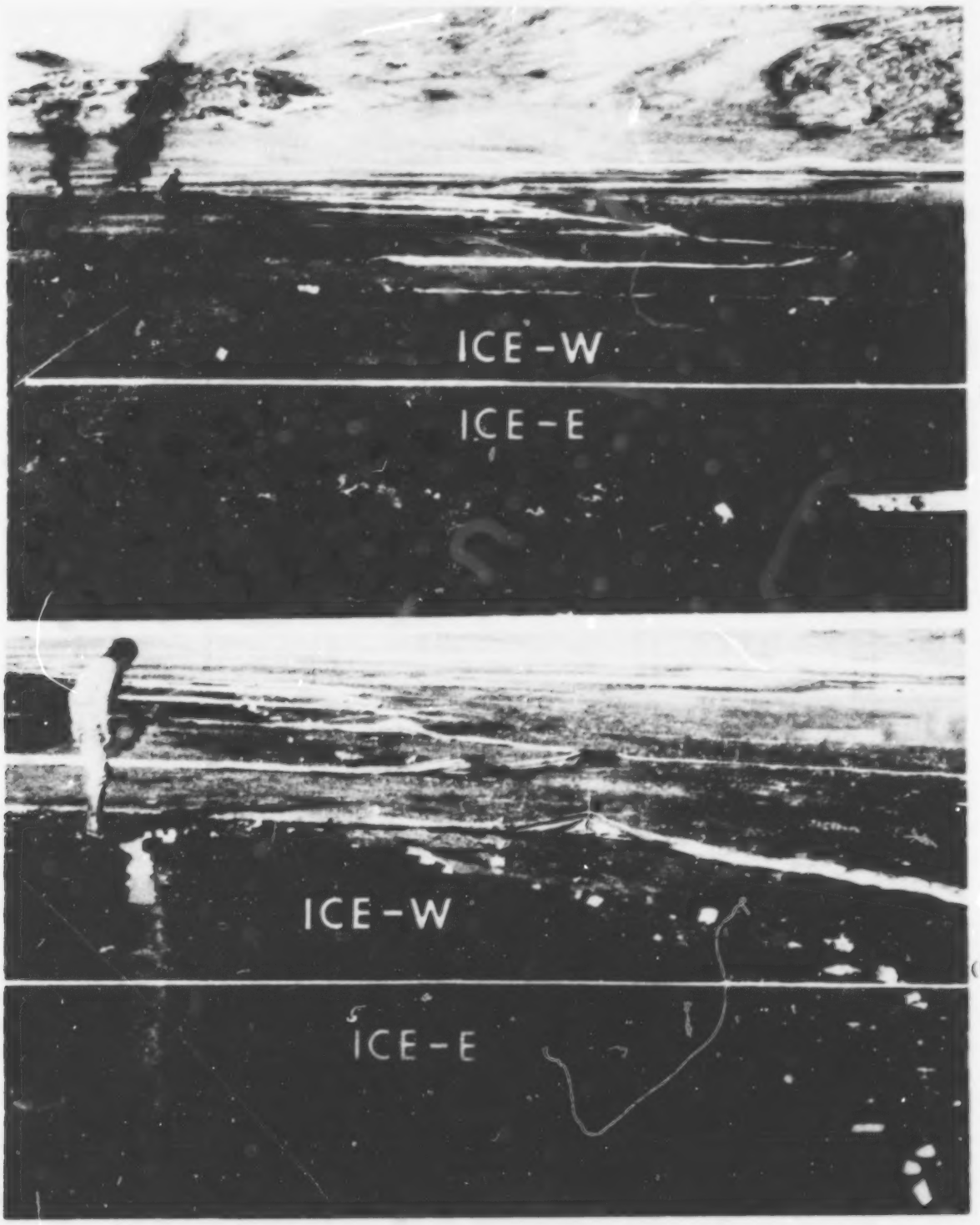


Figure 4.19 (a) Plots ICE-W and ICE-E in the High Water Swash area, 10:15, 13 August 1982.

(b) Plots ICE-W and ICE-E: the original plot, 10:15, 13 August 1982.

4.4.3 BP Dispersant Plots: ID(B)C and ID(B)E

The total hydrocarbon results from the post-test samples indicate high values on both the crude and emulsion plots and in the upper beach zones (Table 4.4). This increase in oil levels is in part due to the composition of the dispersant, which contains hydrocarbons. The fact that levels of hydrocarbon were not reduced following application of the dispersant can be attributed to the fact that the chemical surfactant is designed for use in conjunction with mechanical energy sources, such as wave action, that were not present in this very sheltered environment. Some oil was driven into the subsurface sediments (Table 4.5).

Through time, by 15th September, the presence of some wave activity resulted in a lowering of total hydrocarbon values, although these remained generally higher than those from the control plots in the upper beach area (Table 4.4). Significantly, the level of oil in rows 3 and 4 is considerably higher than on the post-test data sets from all other plots, except the low-pressure flushing plot. This would indicate that the combination of oil, plus a hydrocarbon-based dispersant, and a low wave-energy environment caused a more even distribution of the oil across the zone between the plot and the high-water swash area.

The subsurface oil values (Table 4.5) on 15th September mirror those for the surface samples in that they are both high overall and are particularly high on rows 3 and 4.

The geochemical analyses for both SHWR and the Alkane-Isoprenoid ratio are clearly influenced by the solvents in the dispersant (Table C.3b). These results indicate little of a diagnostic nature with regard to degradation of the dispersed oil.

The BP 1100X dispersant was used in this experiment to obtain data for a direct comparison with the 1981 countermeasures experiments at Crude Oil Point, on a higher energy beach. In a spill situation this dispersant would be used in the intertidal zone on a low-energy intertidal beach with

additional energy inputs; for example, by pushing the contaminated sediments down the beach. Therefore the results of this experiment should be assessed within the context of the overall experimental design and of the intended pupose for which the dispersant was designed.

4.4.4 Exxon Dispersant Plots: ID(E)C and ID(E)E

Total hydrocarbon values were initially (by day +1) reduced significantly on the crude area but were almost unchanged on the emulsion area (Table 4.4). From subsequent sample sets (+7 and +33), relatively few changes can be detected on the crude area. By the end of the sample period, the original plot was relatively clean, whereas the upper intertidal beach surface sediments contained significant amounts of oil. The emulsion plot values changed little from day 0 to day 7, but were reduced an order of magnitude by day 33. More oil remained on the surface sediments of the upper beach areas than on the original plots.

Results of the analysis of subsurface samples (Table 4.5) indicate little initial contamination of the sediments on days 1 and 7, but significantly higher concentrations (1,270 and 2,530 mg/kg) on the upper beach of the crude area by day 33. On the dispersed emulsion area only 5 of 14 samples showed hydrocarbons and no value exceeded 200 mg/kg.

The SHWR ratios for the crude and emulsion show significant evaporative weathering, from barrel values of 3.6 and 3.4 respectively to sample values of 1.7 and 1.4 on 15th September (Table C.3b). By contrast, the ALK/ISO ratios were constant, indicating that no biodegradation occurred during the sampling period.

4.4.5 Low-Pressure Flushing Plot: ICE-E

The effects of low-pressure flushing were to increase total hydrocarbon values significantly on both the original plot and in the high-tide swash areas (Table 4.4). The substantial increase in total-hydrocarbon values on the flushed plot (ICE-E) between day 0 and day

+1 can be attributed to the sampling procedure. Collection of a surface sample involved removal of a layer of sediment to a depth of approximately 5 mm; of which only the top 2 to 3 mm was contaminated by the initial oil distribution. The flushing procedure caused mixing of the entire top 5 mm layer, so that post-test surface samples contained a substantially lower proportion of uncontaminated sediments.

The oil concentrations remained high throughout the sample period, and on both days 7 and 33, the original plot values were the highest of all of the control and experimental plot values (i.e., in row 6, Table 4.4). This is particularly evident in the data for 15th September in which the original plot value of 11,900 mg/kg is almost an order of magnitude greater than that of the other plots. The mean oil-in-sediment value of the samples from rows 2 to 6 on 15 September on the flushed area is 7,400 mg/kg, whereas the next highest similar mean is 4,400 mg/kg, from plot ID(B)C, with mean values on the crude and emulsion control plots of 855 and 2442 mg/kg respectively. For direct comparison, the across-plot means for the three post-test sample sets are 11,272, 10,240 and 5,918 mg/kg, whereas the same values from the adjacent emulsion control plot (ICE-W) are 2,552, 1,242 and 2,000 mg/kg.

The flushing action did not drive oil into the subsurface sediments (i.e., to depths up to 10 cm) to any significant degree (Table 4.5).

The data indicate that low-pressure flushing was not an effective technique for dispersing the oil when compared to the two dispersants, and that less oil was left on the control emulsion plot (ICE-W) than on the flushed emulsion plot.

4.4.6 Mixing Plots: IMC and IME

The backshore plots show considerably higher oil-in-sediment values (Table 4.6) 24-hours following application of the oil (14th August) than the intertidal plots, as there was little oil runoff. The surface total hydrocarbon results indicate an identifiable reduction in the first post-test samples on both mixed plots despite the consistently high concentrations.

Table 4.6 Total Hydrocarbon Results - Backshore Surface Samples (mg/kg)

backbeach	23,800	24,200	42,200	18,400	PRE-TEST 14 August
berm	106,000	56,500	17,100	12,400	
backbeach	20,600	12,700	12,300	34,500	POST TEST 15 August (day 0)
berm	66,900	23,200	9,270	7,730	
backbeach	38,200	14,500	24,800	40,000	POST TEST 22 August (+7 days)
berm	88,600	18,700	13,800	8,640	
backbeach	32,600	18,200	16,700	65,200	POST TEST 15 September (+31 days)
berm	57,100	31,100	8,510	5,350	
	control	mixed	mixed	control	
	IMC		IME		

Table 4.7 Total Hydrocarbon Results - Backshore Subsurface Samples (mg/kg)

backbeach	100	270	360	140	PRE-TEST 14 August
berm	2,200	7,010	17,900	14,500	
backbeach	570	8,400	11,900	120	POST TEST 15 August (day 0)
berm	1,420	-	12,600	11,200	
backbeach	170	9,400	15,100	220	POST TEST 22 August (+7 days)
berm	1,860	26,900	7,670	11,500	
backbeach	590	7,510	15,100	3,050	POST TEST 15 September (+31 days)
berm	7,380	22,500	11,500	12,800	
	control	mixed	mixed	control	
	IMC		IME		

The subsurface results (Table 4.7) indicate a significant increase in values in the backshore on both mixed plots, from 270 on the crude and 360 mg/kg on the emulsion to values that ranged between 7510 to 9400 and 11,900 to 15,100 mg/kg respectively. The subsurface values of the berm area were initially high due to the porous nature of pebble-cobble sediments. The mixing action of the rototiller resulted in an elevation of values on the crude plot but slightly reduced values on the emulsion plot.

Higher levels of evaporative weathering on the mixed plots are evident from the SHWR values (Table C. 3c). On both control plots, the ratios were lowered by 0.3 between 15th August and 15th September, whereas the ratios of the mixed crude and emulsion plots were reduced by 0.6 and 0.7 respectively, between the same dates. The ALK/1S0 ratios show that biodegradation was not a factor in the weathering on any of the plots over the sample period.

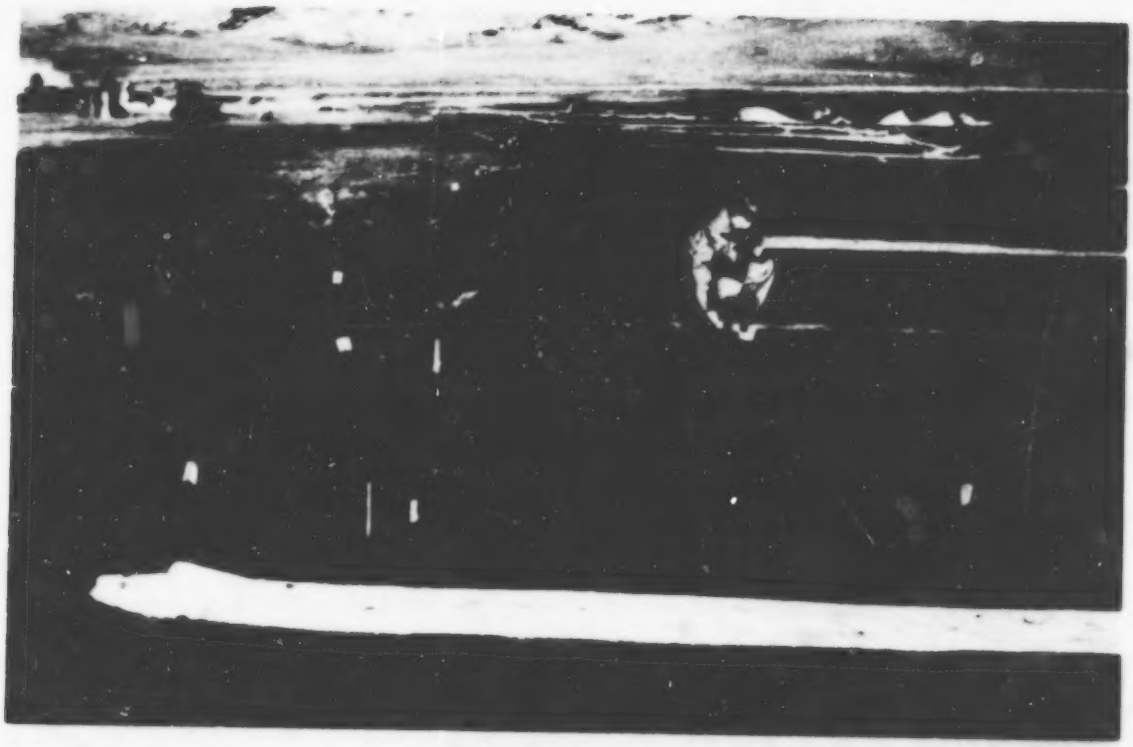
4.4.7 Beach Profiles

The profiles were surveyed on only one occasion (see Appendix A), at the start of the experiments, as no visible alterations to the beach surface were observed.

4.4.8 Discussion

The initial oil loading on the crude plots (mean of 9,400 mg/kg for all three plots) is similar to that for Bay 11, indicating that the experimental conditions were initially suitable to replicate a larger spill situation.

The first flood tide that inundated the plots resulted in a significant redistribution of the oil up the beach (Fig. 4.20). The original plots were approximately 20 m^2 in area, and this was increased by an additional 50 to 80 m^2 of contaminated beach above the plots. Considerably more oil was lifted from the crude plots when compared to the



(a)

(b)

Figure 4.20 (a) Plot ICE-W in the High-Water Swash area, 09:20, 14 August 1982.

(b) Plot ICE-W - the original plot, 09:20, 14 August 1982.

emulsion plots. In particular, total hydrocarbon values on ICC and ID(B)C were reduced by an order of magnitude. Within 24 hours, the mean total hydrocarbon value from the crude plots was reduced by 76 percent, whereas the reduction of the mean from the emulsion plots was 30 percent. In the vicinity of the high-water swash, 4½ times more crude oil accumulated than emulsion.

Little oil, either crude or emulsion, initially penetrated the subsurface sediments due to a combination of the viscosity of the oil, the permeability of the fine-grained sediments and the high water content of the subsurface sediments.

The countermeasure experiments produced significant changes on the low-pressure flushing (ICE-E) and Exxon crude (ID(E)C) plots. In the former case, the mean, surface, across-plot, total hydrocarbon value increased four-fold (2,777 to 11,272 mg/kg), whereas in the latter the value was halved (8,543 to 3,832 mg/kg). The Exxon dispersant produced virtually no change in values on the emulsion plot (ID(E)E). The BP dispersant proved to be ineffective on either plot due to the lack of wave energy to mix the dispersant with the oil. The total hydrocarbon values on this plot were significantly elevated as the dispersant itself contains hydrocarbons.

It is evident from the data sets (Table 4.4) that there is considerable spatial variation in oil concentrations across the beach. Several trends, however, can be readily identified from the three sets. Low-pressure flushing evidently caused considerably more oil to be retained on the beach by comparison with the adjacent emulsion control plot. The technique was therefore considered to be of no value in this experiment and was, in fact, more detrimental than natural cleaning, even in this very low wave-energy environment. The flushing technique did not drive oil deeper into the sediments and subsurface values are similar to those from the control plots. The use of the Exxon dispersant was moderately successful on the crude plot but not on the emulsion. By day 33, some penetration had occurred on the upper beach on the Exxon crude plot (ID(E)C). The BP

dispersant plots retained high surface total hydrocarbon values through to the last data set and by this last sample date, considerable penetration of hydrocarbons was evident on both plots. This latter result is not unexpected considering the experimental context and the intended field use of this dispersant.

The SHWR data indicate that evaporative weathering was active on all except the BP dispersant plots. By the last sample set, values ranged between 1.4 and 1.8, as compared to the barrel sample ratios of 2.7 to 3.6. The ALK/ISO ratios show that no biodegradation occurred during this first open-water season.

The backshore mixing experiment (Fig. 4.21) provides a strong contrast to the intertidal study. The oil content values remained high (>5,000 mg/kg) throughout the sample period, although the mixing action lowered the surface total hydrocarbon values significantly on both plots. The initial penetration of oil was greater on the berm than in the backshore due to the loose packing of the pebble-cobble berm sediments.

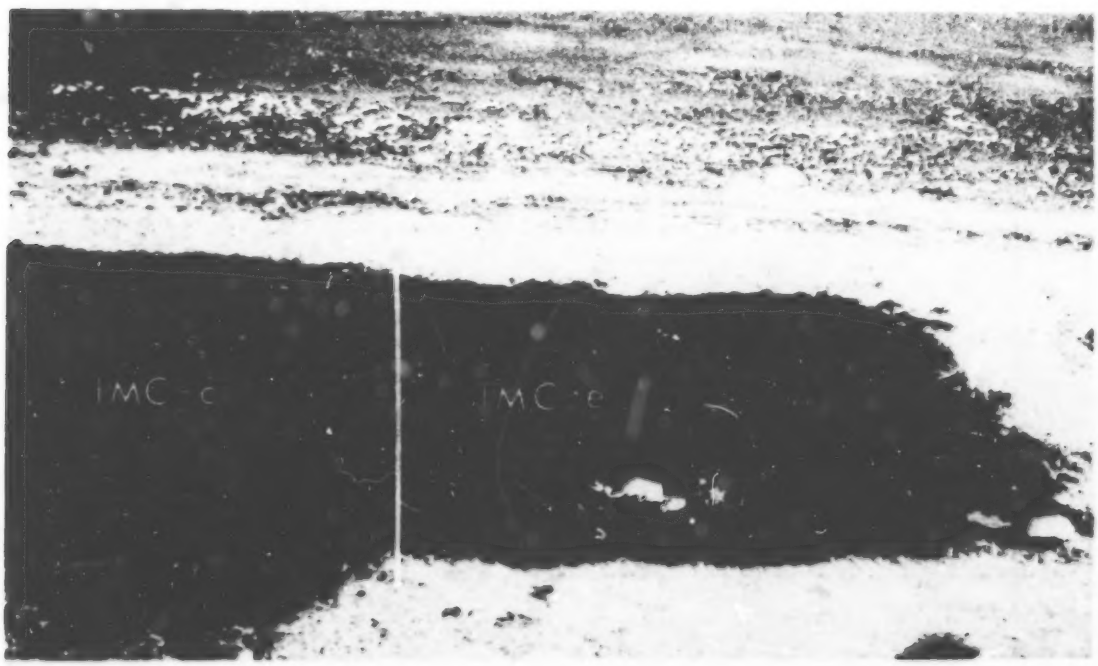


Figure 4.21 Backshore mixed (IMC-c) and control (IMC-e) plot, 15 August 1982, immediately following mixing.

4.5 SUMMARY

The studies conducted in Bay 106 were designed to provide information on the use of dispersants in a very sheltered location and on the effects of mixing in the supratidal zone. The observations in data from the first year of study have indicated several significant points. The initial results are as follows:

- Little oil penetrated the fine-grained intertidal sediments, but there was a major redistribution of the surface oil up the beach by the first flood tide; the crude oil was removed from the plots so that an average of only 25 percent of the original oil remained, whereas on the emulsion plots, 70 percent remained.

- The redistribution of the oil on the upper beach was monitored by a sampling programme which indicated that highest oil contents were at the high-water swash lines of 13 August (the day of oiling) and 14 August; relatively little oil was re-distributed in the area between the plots and the high-water swash lines.

- Low-pressure flushing resulted in significantly higher total hydrocarbon values of the surface samples, in the order of four times greater than the emulsion control plot values.

- The hydrocarbon-based dispersant was designed to penetrate oil and requires either naturally available or added energy to produce the desired dispersing efficiency. The experimental conditions used in 1982 were designed to provide a direct comparison with the 1981 experiments, and in this very sheltered study site insufficient wave energy was available during the sample period to agitate the oil-dipsersant mixtures. Little oil was therefore removed from the study plots.

- The results of the backshore mixing experiment using the rototiller indicate that the procedure caused a reduction in surface total hydrocarbon contents by at least 50 percent.

5.1 INTRODUCTION

A series of intertidal samples was collected along 9 profile lines (Fig 5.1) in "Z-Lagoon", prior to the 1982 experiment, to determine background hydrocarbon levels. Samples were collected across the beach at each site from the centre of the upper, middle, and lower thirds of the intertidal zone.

5.2 RESULTS

The analytical results (Table 5.1) show that very little or no oil was present in the sediments on 10 August 1982. Even though approximately 10 bbl (2.0 m^3) of aged and emulsified oil had been laid down* on the shores of the inlet mouth, during the summers of 1980 and 1981, at Crude Oil Point and at the "L" control site, there has been little redistribution of the oil on to the adjacent beaches within the lagoon.

Table 5.1 Total - Hydrocarbon Analysis Results (in mg/kg) from Intertidal Sediments in "Z-Lagoon".

Location / Site	Upper	Middle	Lower
Z1	0	0	0
Z2	30	0	30
Z3	0	0	0
Z4	30	150	0
Z5	0	0	0
Z6	0	0	0
Z7	30	0	0
Z8	0	0	0
Z9	0	0	0

* This figure is derived from the initial loadings, less the volume of oil recovered.

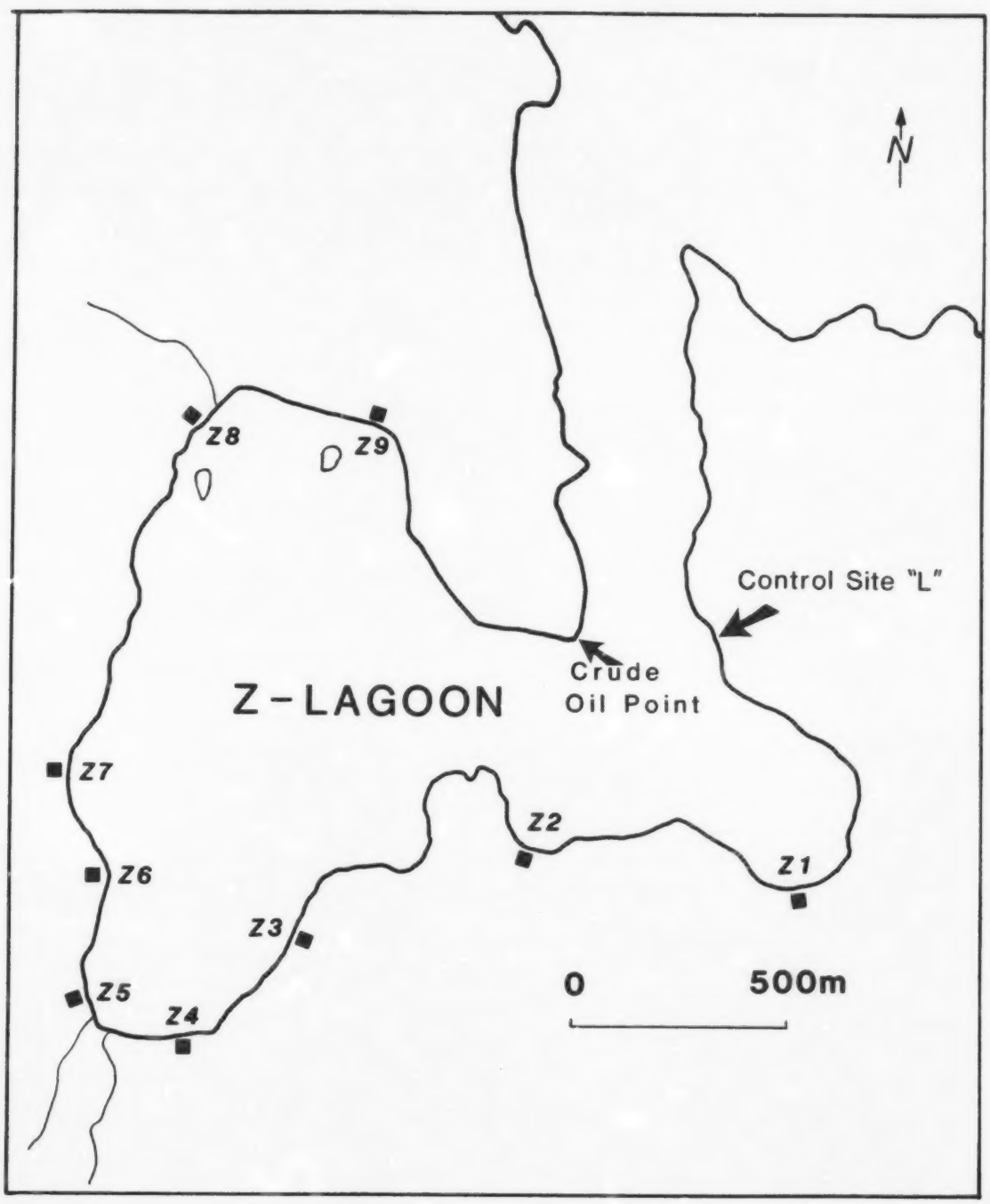


Figure 5.1 Location of sample sites in "Z-Lagoon" for sediment samples collection.

6.1 INTRODUCTION

Two test bays in Ragged Channel were oiled (Fig.1.2) during the 1981 spill experiment, and monitoring studies were initiated on the shoreline contamination of these bays. Crude oil was discharged onto the water surface on Bay 11 and subsequently stranded in the intertidal zone of the bay. A water-oil-dispersant mixture was discharged in Bay 9, and minor amounts of this mixture were stranded in the intertidal zone (Owens et al., 1982a). Additional observations and sampling of shore-zone contamination in these bays were conducted during 1982.

6.2 RAGGED CHANNEL - BAY 9

During and immediately following the initial spill in Bay 9, only minor oiling of the shore zone was noted (Owens et al., 1982a). Observations during 1982 (B. Humphrey, 1982, pers. comm.) indicated no visible signs of oil within the intertidal zone. Total hydrocarbon analyses (Table B.6, Appendix B) of sediment samples collected along three profiles (Fig. 6.1) within Bay 9 (Fig. 5.1) confirm the visual

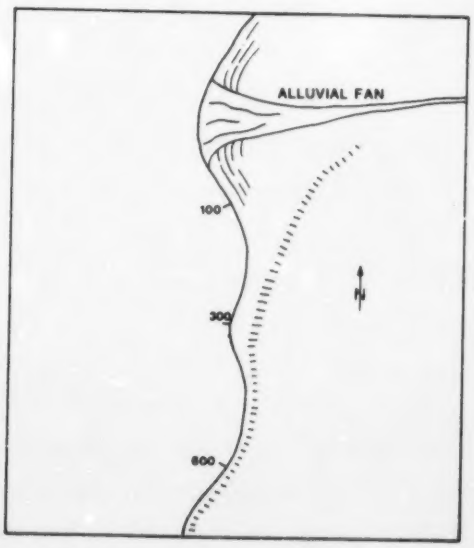


Figure 6.1 Locations of sample sites in Bay 9.

Table 6.1 Total Hydrocarbon Content (mg/kg) of Bay 9 Samples

	28 Aug 1981		12 Aug 1982		
PROFILE	UPPER INTERTIDAL	MIDDLE INTERTIDAL	UPPER INTERTIDAL	MIDDLE INTERTIDAL	LOWER INTERTIDAL
100 surface	1,260	0	0	0	0
subsurface	-	-	0	0	0
300 surface	0	0	0	0	0
subsurface	-	-	0	0	0
600 surface	0	0	0	0	0
subsurface	-	-	0	0	0

Table 6.2 Geochemical Analysis Results: Bay 9

(a) 1981

PROFILE	DATE	SHWR	ALK/ISO
P200-M	31 Aug 81	1.4	-
P200-L	31 Aug 81	1.5	-

(b) 1982

P100-U	8 Aug 82	1.1	1.9
P100-M	8 Aug 82	1.3	3.6
P100-L	8 Aug 82	1.1	2.2
P300-U	8 Aug 82	1.6	2.8
P300-M	8 Aug 82	1.7	3.9
P300-L	8 Aug 82	1.5	3.9

observations. The results (Table 6.1) show that no oil (at the detection limit of the technique) was present within the sediments. Geochemical analyses (Table C.4, Appendix C and Table 6.2) of trace amounts of oil indicate that the oil that is present is well-weathered physically (SHWR range of 1.6 to 1.1), but that little biodegradation of the oil has occurred (ALK/1SO Ratios 3.9 to 1.9). The evaporative weathering occurred prior to the first sample set in late August 1981.

6.3 RAGGED CHANNEL - BAY 11

The intertidal zone of Bay 11 was extensively oiled during 1981 experiments. In 1982, across-shore beach profiles were surveyed, across-shore transects of the oil covering in the intertidal zone were

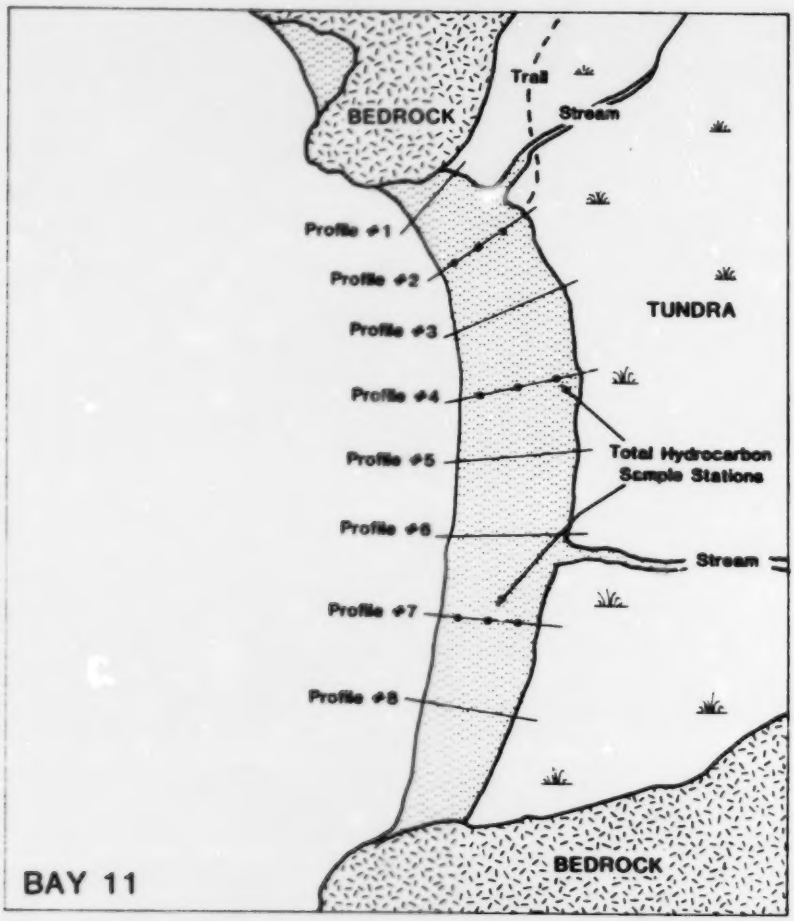
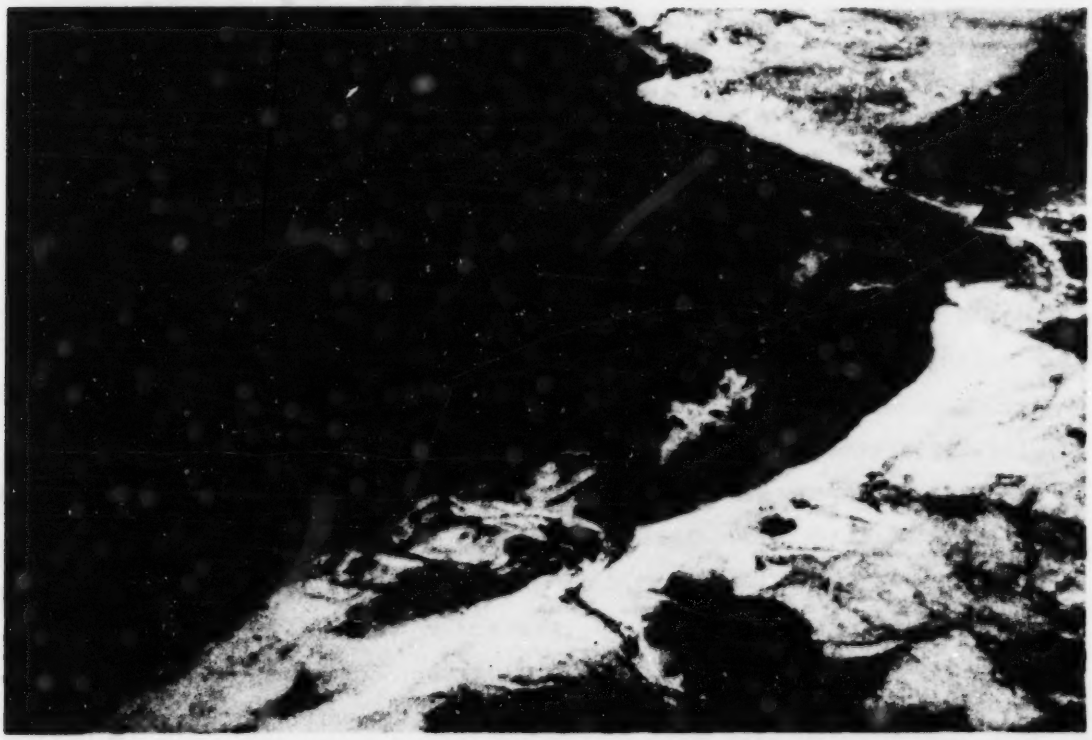


Figure 6.2 Location of surveyed profiles and sample sites in Bay 11.

conducted, and samples were collected for total hydrocarbon and GC/MS analysis. The locations of the various beach profiles, oil covering transects, and sample locations are shown in Figure 6.2.

Observations and data indicate that less oil is present in 1982 in the intertidal zone; however, many sections of the Bay 11 shore zone remain heavily oiled (Fig. 6.3). Areas where muddy-sand material are present had very low initial surface coverings of oil (generally <10%), although in 1982 sheen could be produced on the water surface by mixing of these sediments. Several patches of extremely fresh looking oil were observed in the intertidal zone in 1982, and these areas appeared to correspond with topographic highs. It is thought that these fresh patches of oil represent areas of sediment disturbance due to ice scouring. Fresh oil probably resulted from comparatively unweathered subsurface oil being mixed to the surface. It is unlikely that fresh patches represent oil which has actually been removed from sediments elsewhere and redeposited.

(a)



(b)

Figure 6.3 (a) Comparison of Bay 11 between August 27, 1981, eight days after the oil was stranded, and

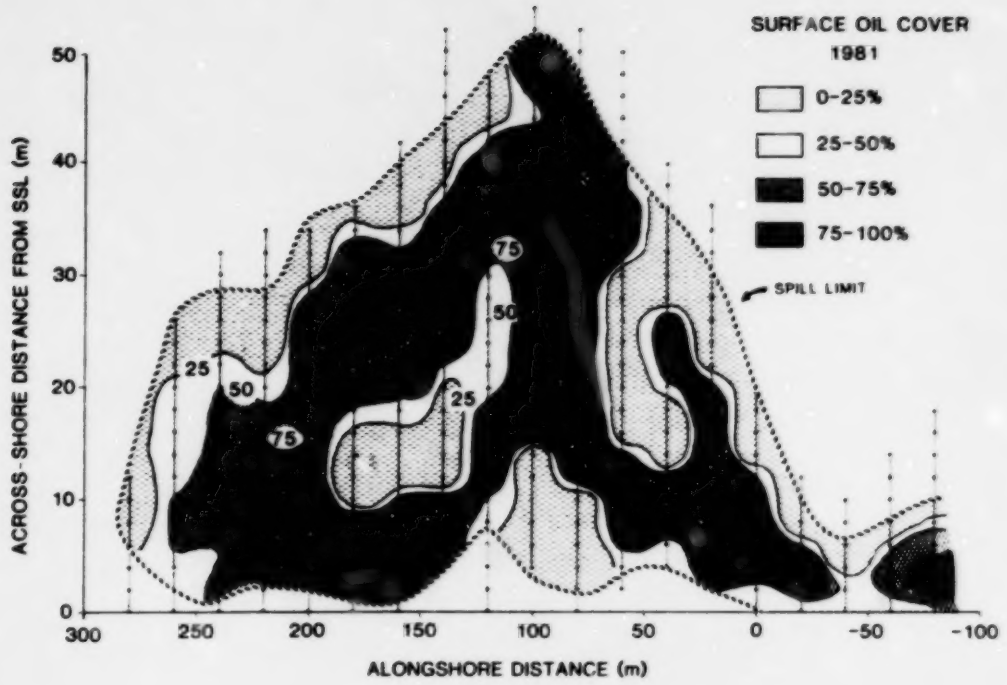
(b) August 14, 1982. A small mast three meters high, is indicated by the arrow near the right margin of both photographs.

6.3.1 Beach Profiles and Oil Cover Surveys

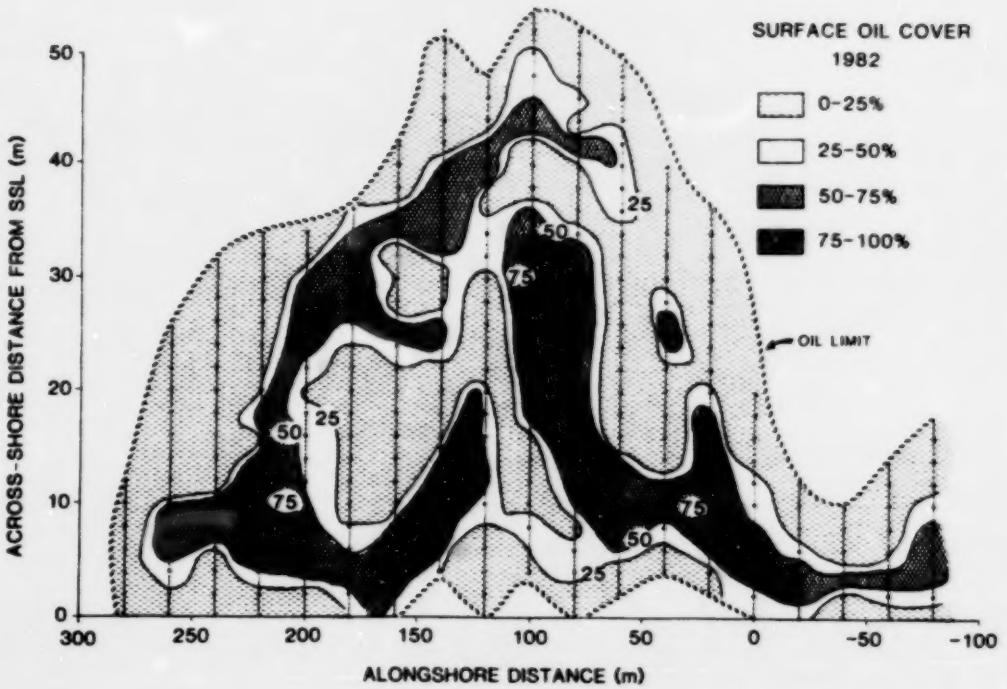
Comparison of surveyed beach profiles (Figs. 6.2 and A-4) indicates that little change occurred to the beach surface between 1981 and 1982 (Fig. A-4). The small changes that are apparent are within the error-bands of the survey technique, and the lack of a consistent trend between profiles supports the concept that no significant beach erosion/accretion events occurred between the surveys. The lack of change is typical for low wave-energy beaches of this type.

Maps of surface oil covering, as determined by visual estimation of surface oil cover every 2 m along lines spaced at a 20 m interval, provide an index of spatial and temporal variations in the distribution of oil within the Bay. A map of the initial oil cover in late August 1981 (Fig. 6.4a) shows that considerable variation of oil cover existed only a short time after the oiling. A survey during 1982 shows similar variations in distribution patterns (Fig. 6.4b), although considerable reduction in oil content had occurred. A comparative map of the two distributions indicates the areas of greatest change (Fig. 6.5): (1) an area of increased oil covering in the upper intertidal zone, where previously unoiled areas were oiled; (2) an area in the mid-intertidal zone where the surface oil cover substantially decreased; and (3) an area in the lower intertidal zone where an increase in surface oil covering occurred. The increase of oil covering in the lower intertidal zone is partially a result of ice reworking and the exposure of oil from the subsurface sediments and partially the result of new areas being oiled.

The mapping comparisons indicate that the contaminated area of the intertidal zone increased by approximately 18 percent as a result of new oiling by redistribution, although the mean surface oil covering of the contaminated areas was reduced from 58.5 to 36.9 percent (Table 6.3). The mean oil cover of the areas defined as newly-oiled in 1982 was 11.9 percent (Table 6.4). Mean surface oil covering values for the upper, middle and lower intertidal zones (Table 6.4) indicate similar trends to those shown on the map. The trends indicate that the lower intertidal zone showed the



(a)



(b)

Figure 6.4 (a) Maps of the oil distribution (% cover) on Bay 11 beaches, 26 August 1981, and

(b) 11 August 1982. (Note: the scale distortion between the along-shore and across-shore axes).

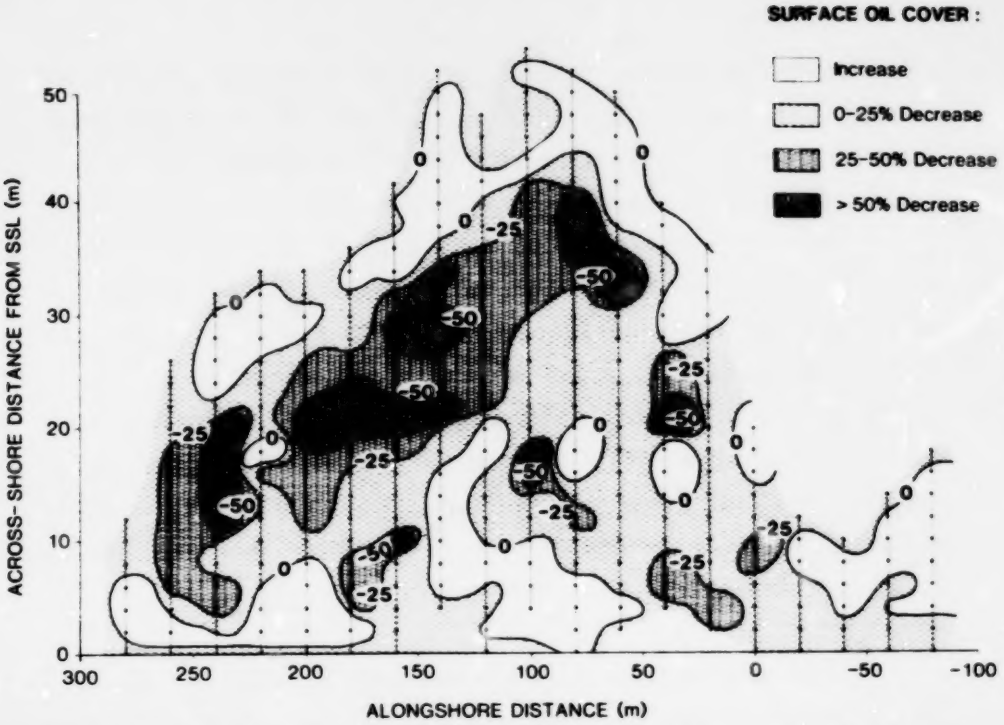


Figure 6.5 Net change of surface oil distribution on Bay 11 between 26 August 1981 (seven days after oiling) and 11 August 1982.

Table 6.3 Bay 11 Surface Oil Cover Characteristics

	Intertidal Oiled Area	Mean Oil Covering
Aug 1981 Survey	9,560 m²	58.5%
Aug 1982 Survey	11,320 m²	36.9%
1981 to 1982 Change	+1,760 m²	-21.6%

Table 6.4 Bay 11 surface oil cover changes between 1981 and 1982

	Area (m²)	% Change
New Areas Oiled	1,760	+11.9%
Upper Intertidal Zone	3,640	- 7.9%
Middle Intertidal Zone	4,400	-24.1%
Lower Intertidal Zone	3,440	- 4.5%

least amount of change, probably because ice exposed fresh subsurface oil, whereas the middle intertidal zone showed the greatest amount of change (i.e., a decrease of 24.1 percent in oil covering).

The visual observation data can be used to develop a comparative analysis of the 1981 and 1982 oil budget. In 1981, 9560 m^2 of the Bay had an average oil cover of 58 percent (Table 6.4). In terms of oil content, this is equivalent to 5,593 m^2 with a 100 percent oil cover. During 1982, 11,320 m^2 of the Bay had an average cover of 37 percent (Table 6.4), which is equivalent to 4,188 m^2 with a 100 percent oil cover. Comparison of the 1981 and 1982 oil cover values (i.e., 5,593 m^2 in 1981 to 4,188 m^2 in 1982) indicates that 75 percent of the initial stranded oil remains in Bay 11 (i.e., a 25% decrease in oil cover).

Wave data collected in 12 m of water in Bay 11 between 14 August and 12 September, 1982, indicate that at no time over that period did wave heights exceed 20 cm. By contrast, data obtained simultaneously from Bay 102 show wave heights greater than 50 cm on at least seven occasions (B. Humphrey; pers. comm). The level of wave-energy in Bay 11 is clearly low, so that changes in the oil cover would be expected to be lower than on the exposed beaches of Bay 102.

6.3.2 Results of Total Hydrocarbon Analyses

Total hydrocarbon analyses of Bay 11 sediment samples are presented in Table 6.5 for the 1981 and 1982 sampling periods. There is considerable scatter in the data and this reflects the considerable spatial variations in oil distributions (Fig. 6.4b). The analyses indicate that high concentrations of oil continue to be found within the Bay. In particular, the following trends are evident:

- surface oil contents remain high with a mean of 4,374 mg/kg in 1982 (range 620 to 11,800 mg/kg),
- subsurface oil contents are lower than surface values with a mean of 1,026 mg/kg in 1982 (range 60 to 5,250 mg/kg), and
- a decrease in both surface and subsurface oil contents in the middle and lower intertidal zone.

Table 6.5 Total Hydrocarbon Content (mg/kg): Bay 11

		1981			1982
		20 Aug	28 Aug	15 Sept	10 Aug
PROFILE 2	upper surface	7,050	2,840	5,920	3,370
	subsurface	90	220	tr	1,180
	mid surface	480	6,400	1,920	4,040
	subsurface	50	320	330	270
	low surface	18,000	4,540	1,860	860
	subsurface	60	190	240	60
PROFILE 4	upper surface	3,440	109	260	9,730
	subsurface	140	140	tr	1,500
	mid surface	4,800	11,000	12,000	2,690
	subsurface	60	110	240	540
	low surface	470	2,050	5,820	620
	subsurface	200	380	tr	160
PROFILE 7	upper surface	16,000	18,000	17,000	11,800
	subsurface	560	5,800	220	5,250
	mid surface	6,090	6,540	6,500	2,190
	subsurface	170	450	360	120
	low surface	7,340	8,270	3,640	4,080
	subsurface	180	500	540	160

Table 6.6 Summary of Total Sediment Hydrocarbon Content (mg/kg)

		1981			1982
		20 Aug (day 0)	28 Aug (day +8)	15 Sept (day +25)	10 Aug
SURFACE	upper intertidal	8,800	7,000	7,100	8,300
	middle intertidal	3,800	7,900	6,800	2,970
	lower intertidal	8,600	5,000	3,800	1,853
	mean	7,100	6,600	5,900	4,374
SUBSURFACE	upper intertidal	260	2,050	70	2,643
	middle intertidal	90	290	310	310
	lower intertidal	150	360	260	126
	mean	170	900	210	1,026

These results are further summarized in Table 6.6. It is evident that there is a strong across-shore gradient in surface oil contents with a mean upper intertidal zone value of 8,300 mg/kg and a mean lower intertidal zone value of 1,853 mg/kg; a similar trend occurs in the subsurface values.

This limited data set provides a basis for evaluating weathering and dispersal of the oil over time. Although there is scatter in the range of total hydrocarbon values, there has been a consistent reduction in sediment oil content over the sampling interval. Mean surface oil contents have been reduced from 7,100 mg/kg at the time of the spill to 5,900 mg/kg at the end of 1981 and to 4,374 mg/kg in 1982 (Table 6.6). A reduction to approximately 40 percent of the initial contents has occurred during one year of weathering. Subsurface oil contents have shown an overall increase since initial oiling, from 170 mg/kg to 1,026 mg/kg. The subsurface trend has not been entirely consistent through time, suggesting that sampling procedures may have introduced some bias; in fact, the mean value for 1982 (Table 6.6) is strongly biased by a single high value. An average of surface and subsurface values is approximately 3,600 mg/kg for the 1981 initial oiling sample set and 2,700 mg/kg for the 1982 samples, suggesting that approximately 75 percent of the initial stranded oil remained on the

Table 6.7 Geochemical Analysis Results: Bay 11

(a) 1981

PROFILE	DATE	SHWR	ALK/ISO
P4-U	20 Aug 81	2.5	2.6
P4-M	-	2.4	2.7
P4-L	-	2.9	2.8
P7-U	-	2.8	2.7
P7-M	-	2.4	2.8
P7-L	-	2.5	2.7
Mean all samples		2.6	2.7
P4-U	15 Sept 81	1.2	1.8
P4-M	-	1.9	2.8
P4-L	-	1.5	2.8
P7-U	-	1.5	2.9
P7-M	-	1.6	2.7
P7-U	-	1.8	2.7
Mean all samples		1.6	2.6

(b) 1982

P2-U	8 Aug 82	1.0	1.0
P2-M	8 Aug 82	1.2	1.1
P2-L	8 Aug 82	1.1	0.6
P7-U	8 Aug 82	1.2	1.8
P7-M	8 Aug 82	1.1	0.9
P7-L	8 Aug 82	1.2	1.3
Mean all samples		1.1	1.1

Bay in 1982 (i.e., a 25% reduction in oil content). This estimate is in close agreement with the estimate that was obtained from the visual observations.

6.3.3 Results of Geochemical Analyses

The geochemical analyses and diagnostic ratios (Tables C.4, in Appendix C, and 6.7) provide further information on the fate of the stranded oil. The range of values for the SHWR was between 2.9 and 1.2 in 1981 (Boehm *et al.*, 1982) and between 1.2 and 1.0 in 1982, indicating that significant evaporative weathering had occurred. As is evident from Table 6.7, the evaporative weathering occurred primarily between 20 August and 15

September 1981, and the mean value of all samples decreased from 2.6 to 1.6. The change between the 15 September 1981 data and that of 8 August 1982 is significant (mean values 1.6 to 1.1) but of a lesser magnitude. The ALK/1SO ratios showed significant changes between 1981 and 1982; the ratios for 1981 ranged from 2.9 to 1.8 (Boehm, 1982), whereas those for 1982 ranged from 1.8 to 0.6, indicating that biodegradation of the oil was significant by the second year of weathering. The mean values show little change between the two 1981 sample sets, but a very large reduction by the August 1982 sample date.

6.4 SUMMARY

Monitoring of the Bay 9 water-oil-dispersant spill and of the Bay 11 crude oil spill provides information on the fate of oil stranded in the shore zone that can be used for comparison with the experimental studies in the "Z-Lagoon" area. In particular, the Bay 11 spill is of significant value as this provides data from a relatively large spill (approx. 50 bbl of oil on the beach) that contrasts to the the smaller spills (in the order of 2 bbl per plot) that were conducted in the "Z-Lagoon area". The primary results of the Ragged Channel studies to date are as follows:

- Effectively no oil is present on the Bay 9 beaches, indicating that the use of dispersants was effective in preventing significant contamination of the shore zone by floating oil.
- Sediment oil contents on Bay 11 beaches remain relatively high after a period of one year. Mean surface values are in the order of 4,000 mg/kg with mean subsurface values in the order of 1,000 mg/kg.
- Significant spatial variation exists in the distribution of oil on the shore zone; in particular, highest sediment oil contents occur in the upper intertidal zone with lowest values in the lower intertidal zone.
- Oil budget estimates, both from visual estimates of oil covering and from total hydrocarbon analyses, indicate that 75% of the oil that was initially stranded remains in Bay 11 after one year (i.e., a 25% reduction of oil has occurred).
- Geochemical analyses of oil stranded within Bay 11 indicate that evaporative weathering was most active during the first open-water season but continued to be a significant process through into 1982, whereas biodegradation has occurred only between the mid-September 1981 and early August 1982 sample periods.

7.0 SUMMARY

The primary results to date from the individual studies are summarized separately at the end of each section. This discussion focusses on some of the more general points that have emerged from the study and that relate to the overall data set, rather than to one particular experiment or study.

The countermeasure tests have provided data that show significant results. The general points are as follows:

(a) low-pressure flushing did not reduce the volume of oil on the beach where the sediments were predominantly fine-grained sands.

(b) dispersants initially lowered total hydrocarbon concentrations, except where the hydrocarbon-based dispersant was not effective in Bay 106, as there was insufficient wave-energy

(c) mixing by rototiller promoted reduction of surface total hydrocarbons in the supra-tidal zone but did little to increase weathering on the intertidal plots, and

(d) solidified oil remained on the beach and was almost unaffected by wave action after one year.

In all cases, the initial loading of crude oil was greater than that of the emulsion, in many cases by double the oil concentration (in terms of milligrams of oil per kilogram of sediment). On the Bay 106 plots, the crude oil was lifted more readily by the rising tide than was the emulsion, but on the Bay 103 plots (L-1 and L-2), the emulsion was removed more rapidly than the crude during the first open-water season. On all plots, the greatest changes in oil volume occurred during the first open-water period following application of the oil.

The evaporative weathering data (the Saturated Hydrocarbon Weathering Ratio) indicate a general trend of considerable change during the first year, up to the first sample set of the second open-water season, and thereafter little or no major changes in the ratio. The weathering process is the loss of the light ends of the spilled oil. Biodegradation (the Alkane-Isoprenoid Ratio) was rarely evident during the first year's sample sets but significant activity was indicated by the data from the second year on the intertidal plots. The data for the backshore plots show no significant biodegradation even where data exist for a three year sample period.

The studies have been conducted in different shore-zone environments in terms of (a) exposure to waves during the open-water season, and (b) sediment characteristics. It is too early in the study to predict the fate or persistence of oil from the very sheltered sand beach of Bay 106, but already it is evident that oil behaved very differently on this beach than it did on the more pebble-cobble dominated beaches of the other "Z-Lagoon" sites. In addition to the lack of oil penetration, it was evident in Bay 106 that oil was more easily redistributed than on the coarser beaches.

Results from the "Z-Lagoon" studies show clearly that small amounts of oil were removed rapidly, even on a shore that has a fetch of only 90 km and an open-water season in the order of 12 weeks. Both the Bay 102 and Crude Oil Point beaches were naturally cleaned for the most part during the first open-water season. Although Bay 11 still appeared heavily contaminated during the second open-water season, nevertheless 25 percent of the stranded oil had been removed in this sheltered environment. The rate of oil removal may have been slower on this beach than on the plots, but significant physical removal of the stranded oil had taken place.

The beach profiles show a relationship between wave-energy levels at the beach and rates of sediment redistribution. Relatively large beach profile changes (and therefore high rates of sediment redistribution) occurred on the exposed, high-energy beach (Bay 102). Changes also

occurred, but were of a smaller magnitude, on the east-facing beaches of Crude Oil Point. In Bays 103, 106 and 11 (the low wave-energy environments), profile changes were either small or negligible. The relationships between sediment redistribution or beach profiles changes and wave-energy levels and between the persistence of stranded oil and changes in beach profiles have been established by previous studies.

The observations and data from Bay 11 provide an important perspective for the "Z-Lagoon" studies. Although the SHWR and ALK/ISO trends are the same for both, the rate of oil removal was considerably lower in Bay 11 than on any of the sheltered "Z-Lagoon" intertidal plots. Thus, although the same processes have operated in the two situations, the oil on the Bay 11 beaches was largely redistributed within the oiled area rather than being spread out over adjacent unoiled areas. The key factor here appears to have been the volume of oil rather than the oil loading. On the experimental and control plots the oil loading (in terms of cm^3 of oil per cm^2 of beach) was in the same range as that of the Bay 11 spill. The volume of oil laid down on the experimental or control beaches, however, was considerably smaller than in Bay 11. The important conclusion from a comparison of the results from the studies in the "Z-Lagoon" area with those from Bay 11 is that small, controlled spills behave in a somewhat different manner, in terms of fate and persistence, than does a large spill. The results of studies and experiments conducted on small plots can be calibrated to real-world situations more accurately if data are available from a larger, similar spill.

APPENDIX A - BEACH PROFILES

Profiles have been surveyed at the experimental and control sites. These cross-beach profiles were surveyed with a self-levelling level. The profile sets presented in this Appendix are composite plots of all profiles surveyed along each line since the initiation of the project.

The profile sets are as follows:

Figure	A.1	Control Plots "H" and "L"
Figure	A.2	Crude Oil Point
Figure	A.3	Bay 106
Figure	A.4	Ragged Channel

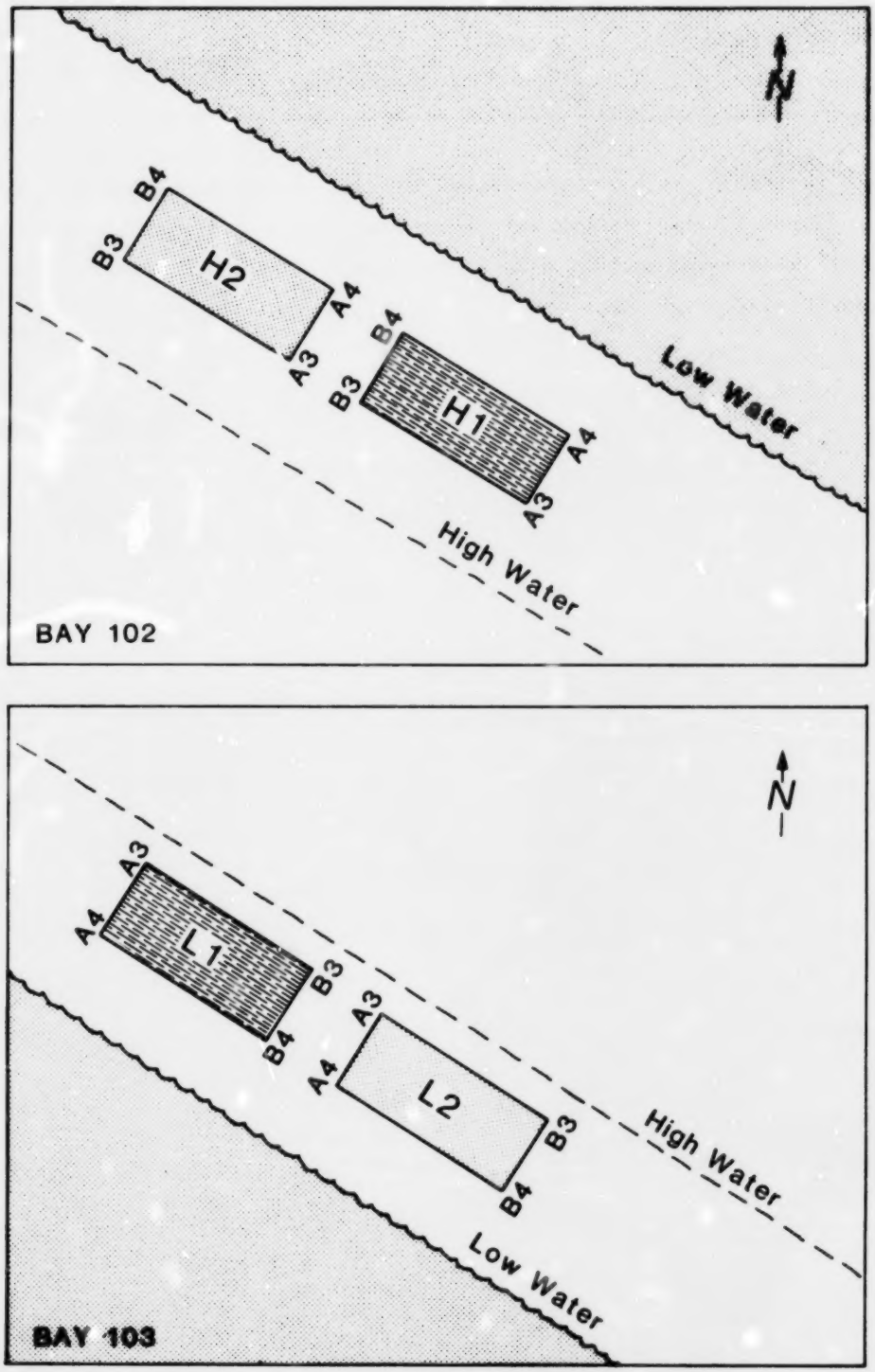


Figure A-1a Location of Profiles on plots H-1 and H-2 (Bay 102) and on plots L-1 and L-2 (Bay 103).

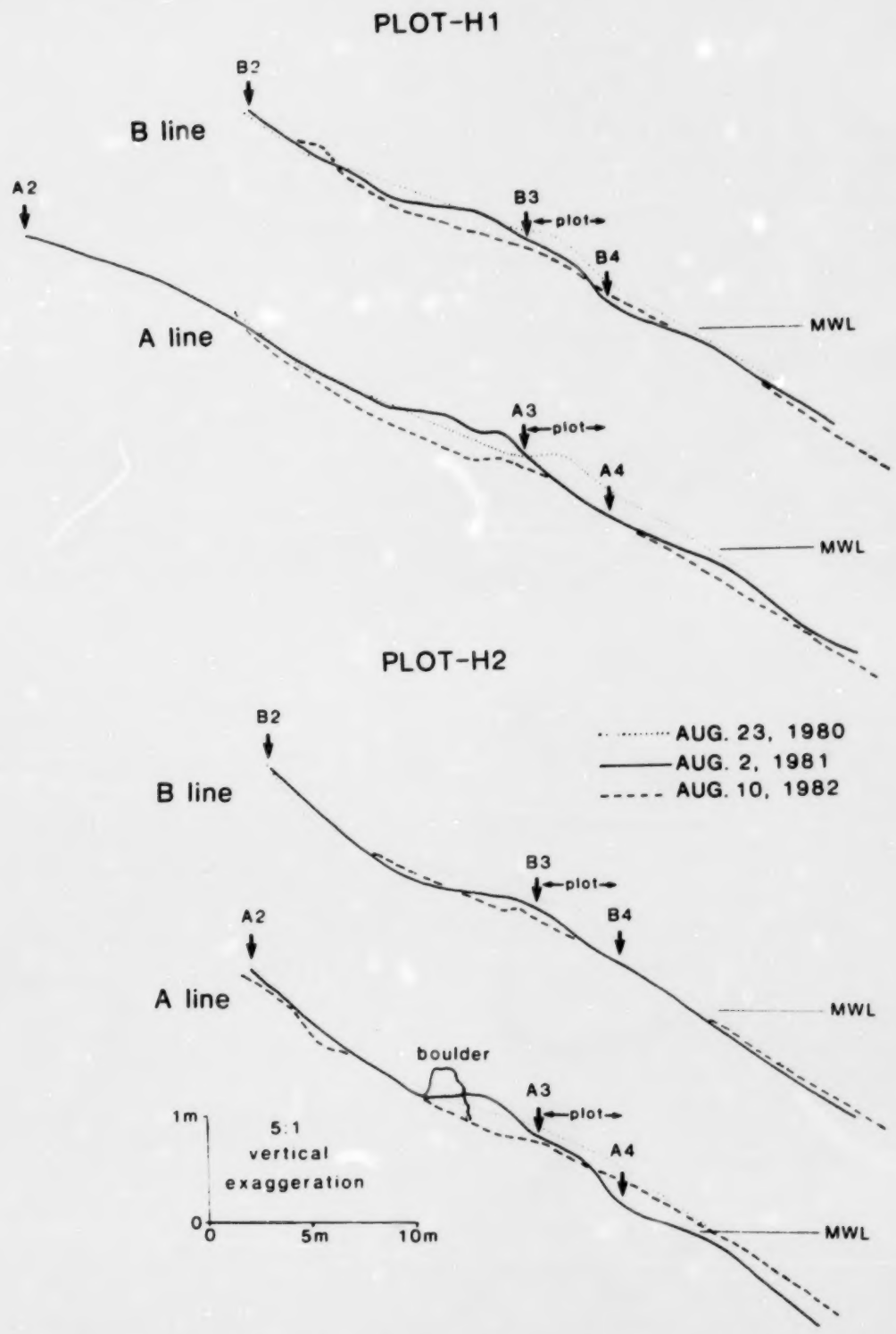


Figure A-1b Across-shore beach profiles of plots H-1 and H-2 (Bay 102). The relative position of the profiles is shown on the sketch map (Fig. A-1a).

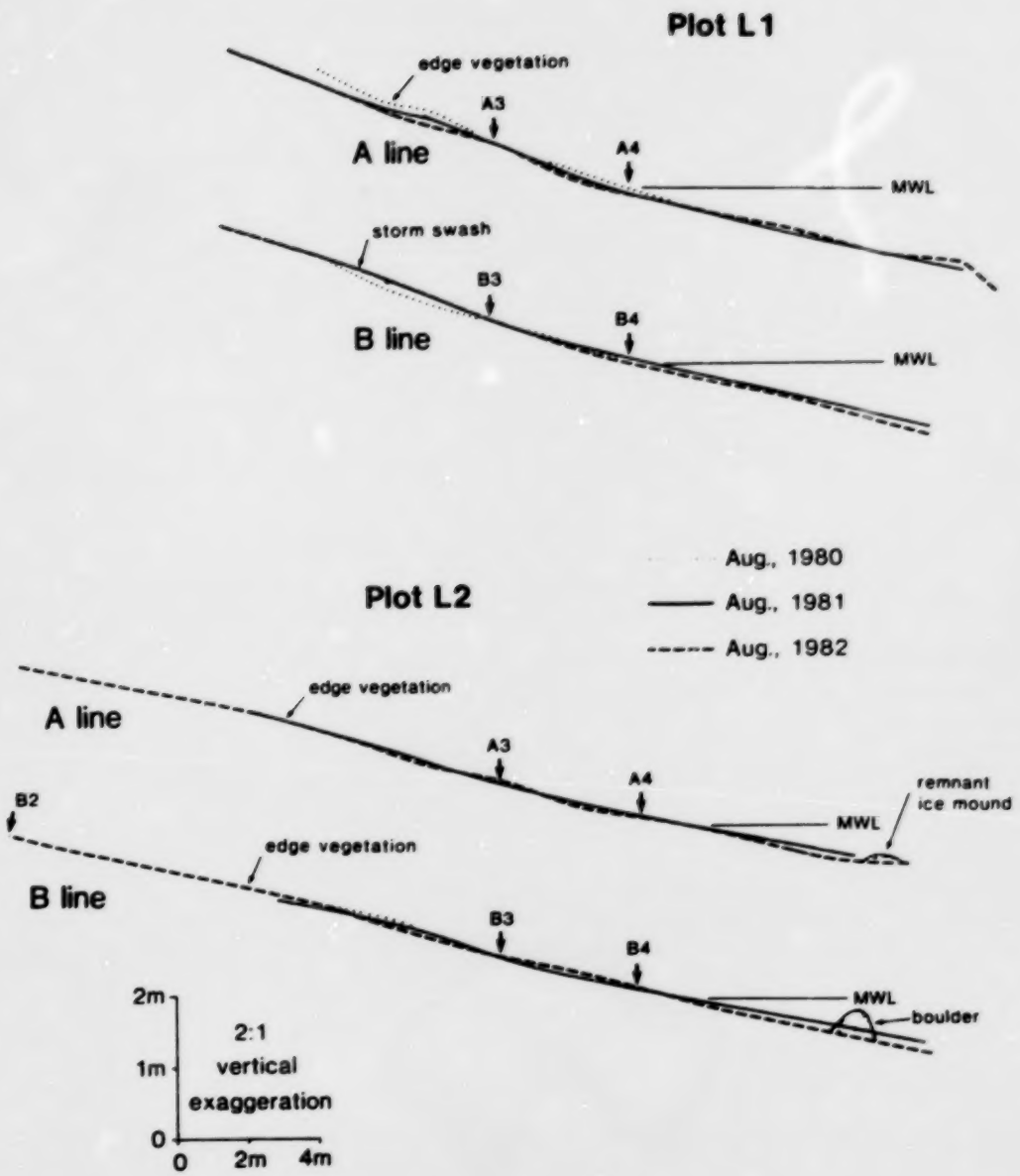
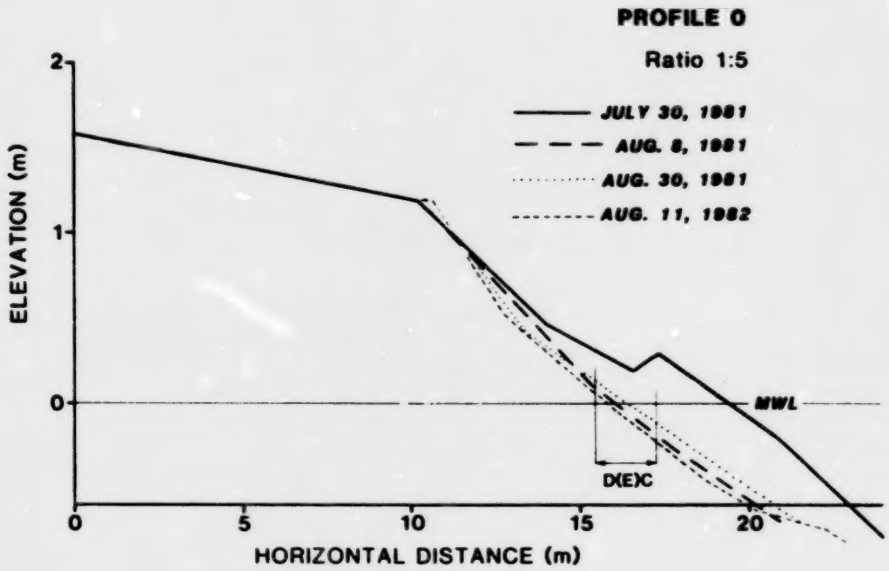


Figure A-1c Across-shore beach profiles of plots L-1 and L-2 (Bay 103). The relative position of the profiles is shown on the sketch map (Fig. A-1a). Previously surveyed profiles are shown only for areas of measurable change.



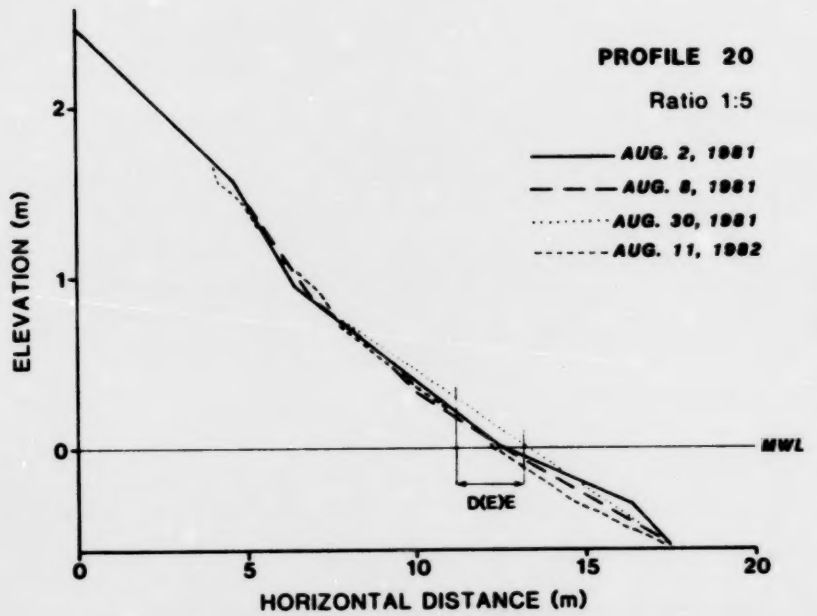
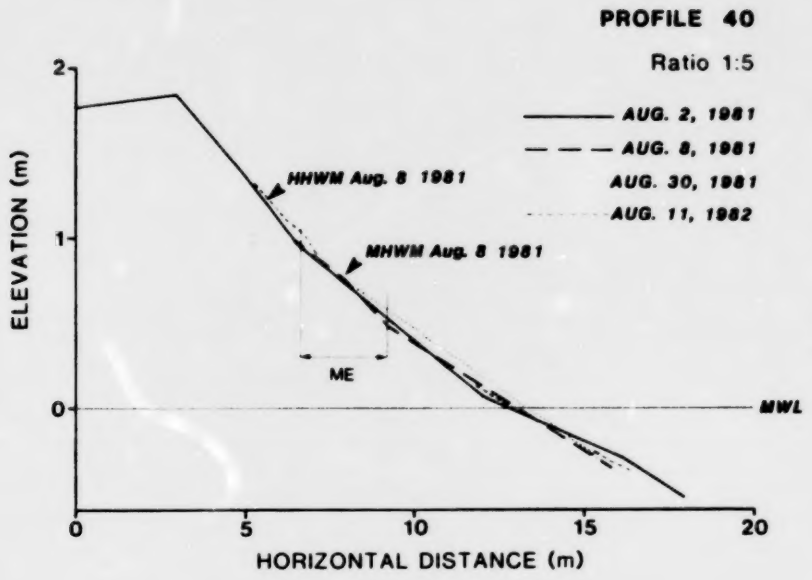


Figure A.2 Profiles surveyed at Crude Oil Point during 1981 and 1982. The location of the profile lines is shown on Figure 3.2 (page 3.2).



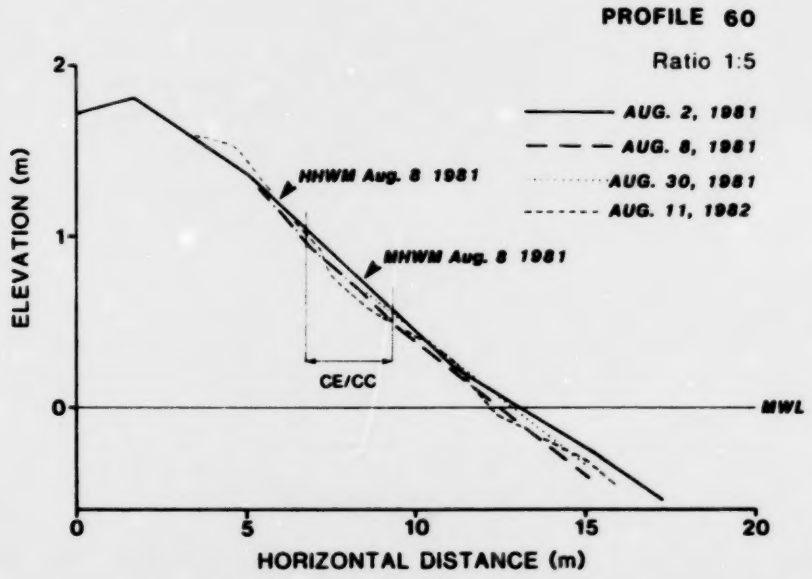
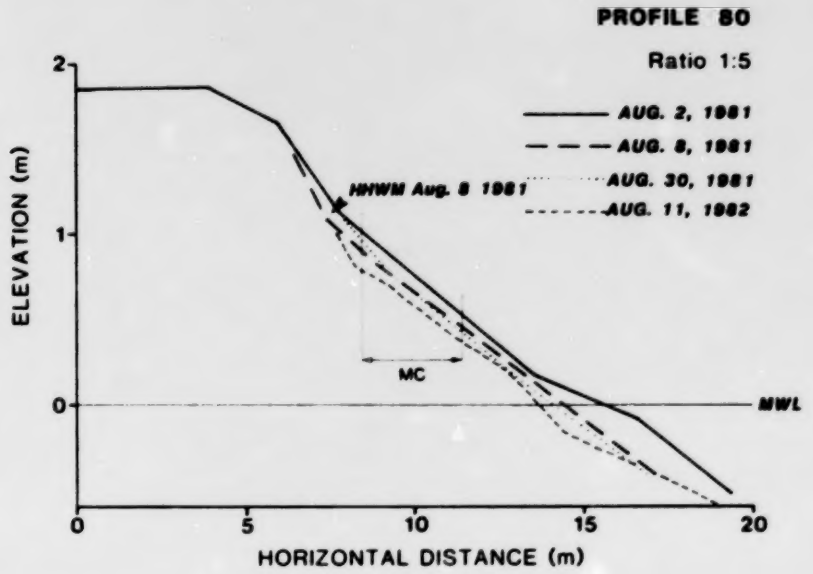


Figure A.2 (cont'd)



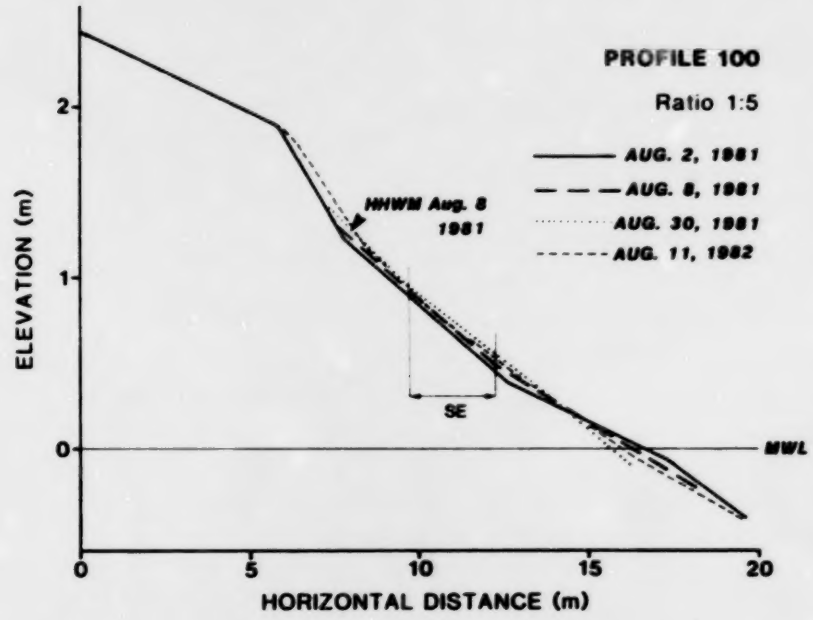
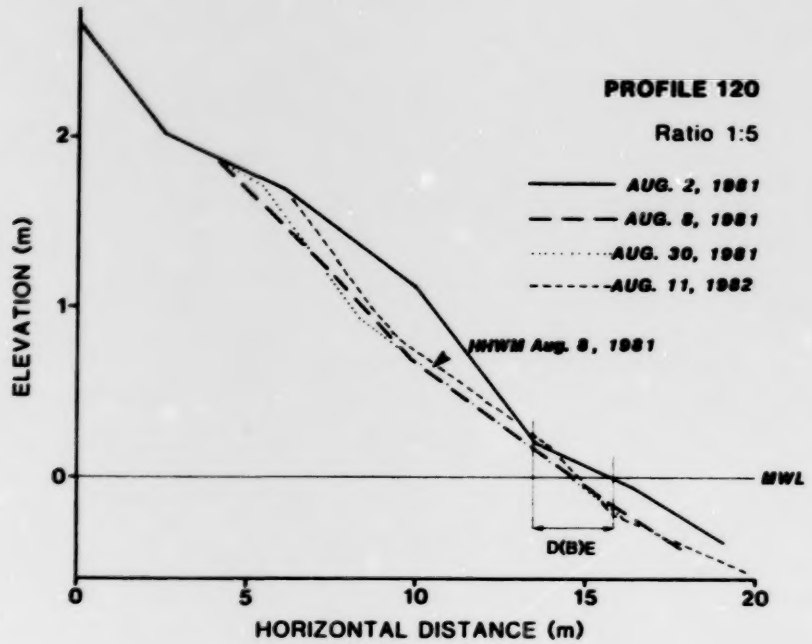


Figure A.2 (cont'd)



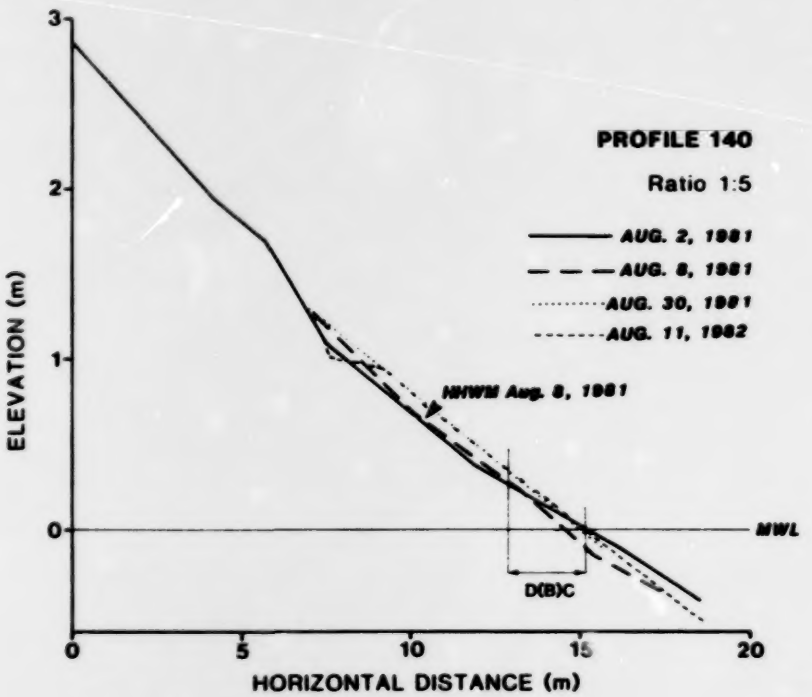


Figure A.2 (cont'd)

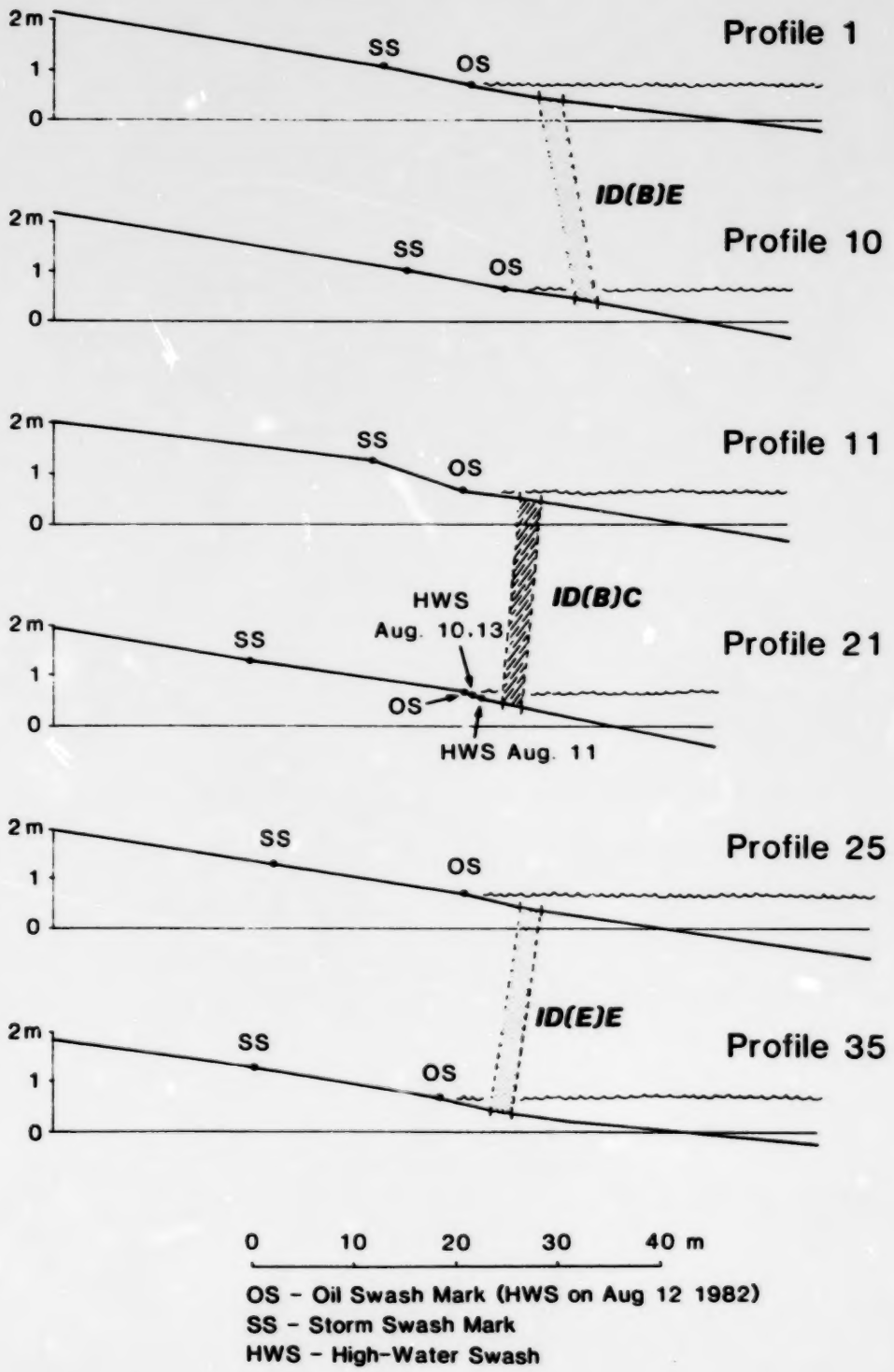


Figure A-3 Profiles surveyed on Bay 106, 15 August 1982. The profile lines are presented on Figure 4.7 (page 4-9).

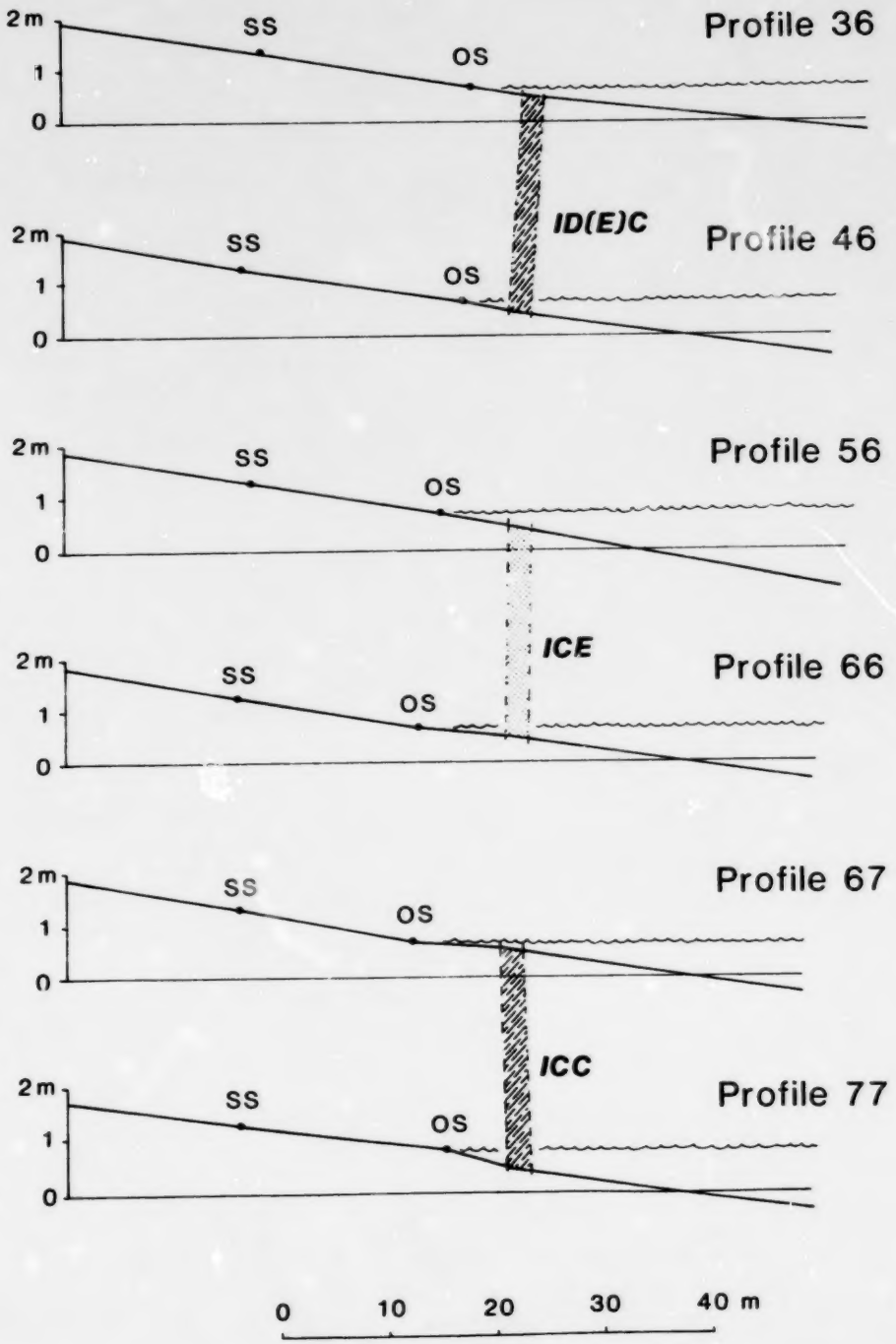


Figure A-3 (cont'd)

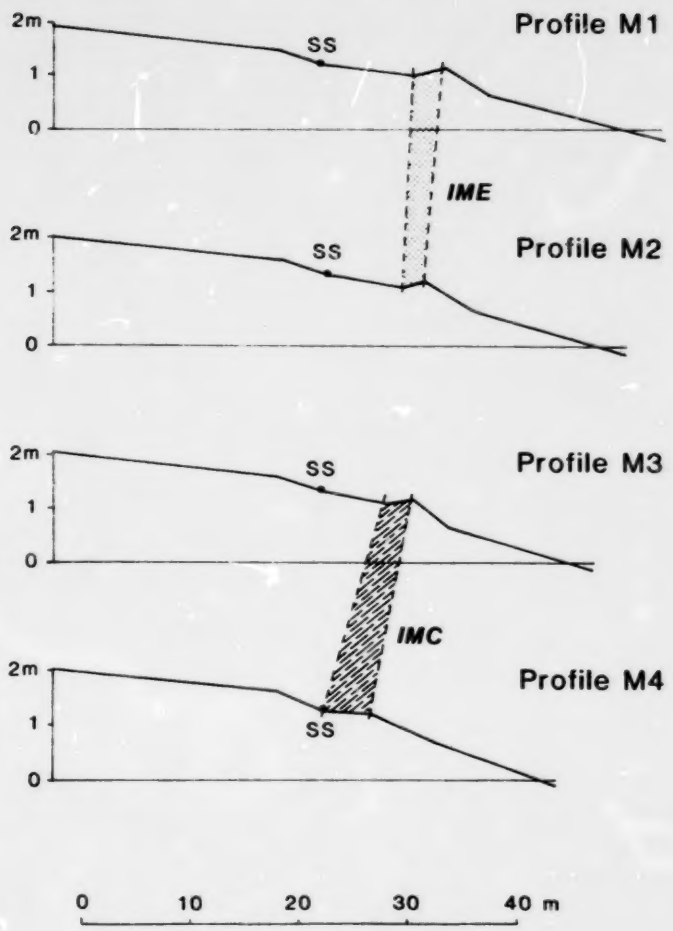


Figure A-3 (cont'd)

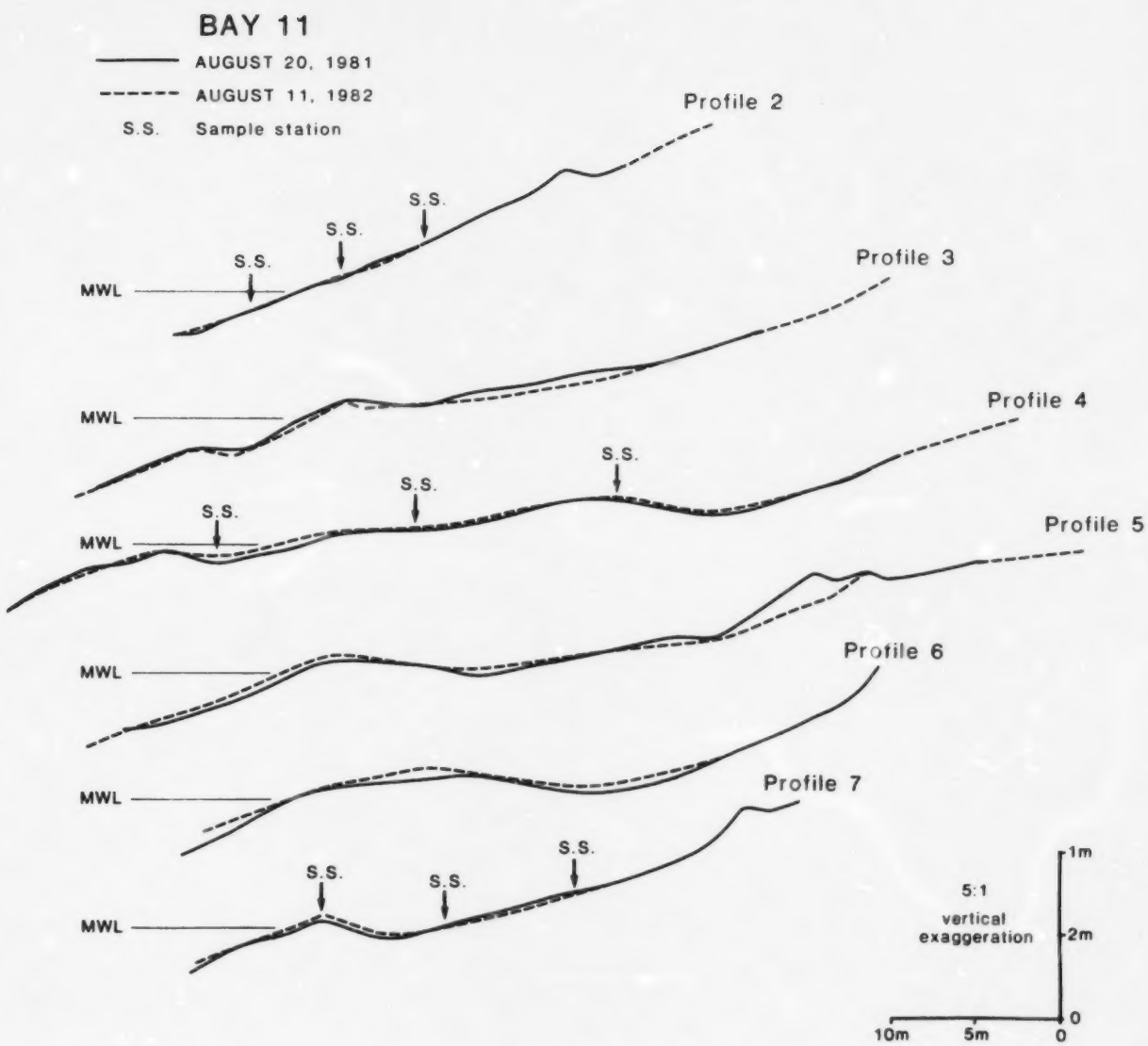


Figure A-4 Profiles surveyed on Bay 11 during 1981 and 1982. Profile lines are given on Figure 6.2 (page 6-3).

APPENDIX B - TOTAL HYDROCARBON ANALYSES RESULTS

Sample collection and analyses were conducted by Seakem Oceanography Ltd. The sampling procedures and the techniques used to analyze for total extractable hydrocarbons are described by Humphrey (1983). The infra-red hydrocarbon analysis yields data that are a weight of extracted hydrocarbon per total weight of sample (mg/kg).

The notation "DL" indicates that the results are at the detection limits or lower of the equipment (approximately 30 mg/kg). In the text tables, the DL notation has been substituted by a zero value.

The tables presented in this Appendix represent the following data sets:

Table B.1	1980 Control Plots
Table B.2	1981 Experimental and Control Plots
Table B.3	1981 Norwegian Plots
Table B.4	1982 Experimental and Control Plots
Table B.5	1982 "Z-Lagoon" Survey
Table B.6	Ragged Channel Beaches

TABLE B.1 Results of Analyses from Samples Collected during 1982 from 1980 Control Plots

Sample No.	Date	Plot	Location	t-h (mg/kg)
S3001	10 August	H1	upper-surface	DL
S3002	10 August	H1	upper-subsurface	DL
S3003	10 August	H1	mid-surface	DL
S3004	10 August	H1	mid-subsurface	DL
S3005	10 August	H1	lower-surface	DL
S3006	10 August	H1	lower-subsurface	DL
S3007	10 August	H2	upper-surface	DL
S3008	10 August	H2	upper-subsurface	DL
S3009	10 August	H2	mid-surface	DL
S3010	10 August	H2	mid-subsurface	DL
S3011	10 August	H2	lower-surface	DL
S3012	10 August	H2	lower-subsurface	DL
S3013	10 August	L1	upper-surface	2 150
S3014	10 August	L1	upper-subsurface	15 700
S3015	10 August	L1	mid-surface	1 750
S3016	10 August	L1	mid-subsurface	9 830
S3017	10 August	L1	lower-surface	5 540
S3018	10 August	L1	lower-subsurface	3 030
S3019	10 August	L2	upper-surface	DL
S3020	10 August	L2	upper-subsurface	DL
S3021	10 August	L2	mid-surface	DL
S3022	10 August	L2	mid-subsurface	DL
S3023	10 August	L2	lower-surface	230
S3024	10 August	L2	lower-subsurface	DL
S3025	10 August	T1	surface	28 300
S3026	10 August	T1	subsurface	15 800
S3027	10 August	T2	surface	16 700
S3028	10 August	T2	subsurface	16 800
S3029	10 August	TE1	surface	24 700
S3030	10 August	TE1	subsurface	40 400
S3031	10 August	TE2	surface	44 900
S3032	10 August	TE2	subsurface	24 300
S3051	2 September	H1	upper-surface	DL
S3052	2 September	H1	upper-subsurface	DL
S3053	2 September	H1	mid-surface	DL
S3054	2 September	H1	mid-subsurface	DL
S3055	2 September	H1	lower-surface	DL
S3056	2 September	H1	lower-subsurface	DL
S3057	2 September	H2	upper-surface	DL
S3058	2 September	H2	upper-subsurface	DL
S3059	2 September	H2	mid-surface	DL
S3060	2 September	H2	mid-subsurface	DL
S3061	2 September	H2	lower-surface	DL
S3062	2 September	H2	lower-subsurface	DL

TABLE B.1 (Cont'd.)

Sample No.	Date	Plot	Location	t-h (mg/kg)
S3063	2 September	L1	upper-surface	2 580
S3064	2 September	L1	upper-subsurface	8 480
S3065	2 September	L1	mid-surface	11 500
S3066	2 September	L1	mid-subsurface	13 200
S3067	2 September	L1	lower-surface	440
S3068	2 September	L1	lower-subsurface	3 840
S3069	2 September	L2	upper-surface	DL
S3070	2 September	L2	upper-subsurface	DL
S3071	2 September	L2	mid-surface	40
S3072	2 September	L2	mid-subsurface	DL
S3073	2 September	L2	lower-surface	DL
S3074	2 September	L2	lower-subsurface	DL
S3075	2 September	T1	surface	28 700
S3076	2 September	T1	subsurface	14 700
S3077	2 September	T2	surface	17 800
S3078	2 September	T2	subsurface	13 500
S3079	2 September	TE1	surface	23 600
S3080	2 September	TE1	subsurface	3 390
S3081	2 September	TE2	surface	36 200
S3082	2 September	TE2	subsurface	29 600

TABLE B.2 Results of Analyses from Samples Collected during 1982 from 1981 Countermeasure Experiments and Control Plots

Sample No.	Date	Plot	Location	t-h (mg/kg)
S3101	10 August	D(E)C	surface	80
S3102	10 August	D(E)C	subsurface	900
S3103	10 August	D(E)E	surface	130
S3104	10 August	D(E)E	subsurface	170
S3105	10 August	ME	surface	230
S3106	10 August	ME	subsurface	1 070
S3107	10 August	CE	surface	90
S3108	10 August	CE	subsurface	390
S3109	10 August	CC	surface	300
S3110	10 August	CC	subsurface	3 380
S3111	10 August	MC	surface	160
S3112	10 August	MC	subsurface	1 240
S3113	10 August	D(B)E	surface	DL
S3114	10 August	D(B)E	subsurface	DL
S3115	10 August	D(B)C	surface	DL
S3116	10 August	D(B)C	subsurface	30
S3151	2 September	D(E)C	surface	90
S3152	2 September	D(E)C	subsurface	50
S3153	2 September	D(E)E	surface	370
S3154	2 September	D(E)E	subsurface	260
S3155	2 September	ME	surface	100
S3156	2 September	ME	subsurface	450
S3157	2 September	CE	surface	500
S3158	2 September	CE	subsurface	300
S3159	2 September	CC	surface	80
S3160	2 September	CC	subsurface	220
S3161	2 September	MC	surface	140
S3162	2 September	MC	subsurface	2 280
S3163	2 September	D(B)E	surface	DL
S3164	2 September	D(B)E	subsurface	DL
S3165	2 September	D(B)C	surface	DL
S3166	2 September	D(B)C	subsurface	DL

TABLE B.3 Results of Analyses from Samples collected during 1982 from the 1981 Norwegian Plots

Sample No.	Date	Location	t-h (mg/kg)
S3136	10 August	H surface	20 200
S3137	10 August	H subsurface	2 020
S3138	10 August	G surface	19 800
S3139	10 August	G subsurface	50
S3140	10 August	F surface	21 600
S3141	10 August	F subsurface	210
S3142	10 August	E surface	15 900
S3143	10 August	E subsurface	DL
S3144	10 August	D oiled layer at 5-10 cm	DL
S3751	22 August	fertilized plot	80 000
S3752	22 August	fertilized plot	86 100
S3753	22 August	fertilized plot	44 900
S3754	22 August	fertilized plot	46 200

TABLE B.4 Results of Analyses from Samples Collected from 1982 Experimental and Control Plots

Sample No.	Date	Plot	Sample Schedule	Location	t-h (mg/kg)
S3401	12 August	ID(E)C	pre-test	surface-plot	4 090
S3403	12 August	ID(E)E	pre-test	surface-plot	4 850
S3405	12 August	ID(B)C	pre-test	surface-plot	8 810
S3407	12 August	ID(B)E	pre-test	surface-plot	8 280
S3409	12 August	ICC	pre-test	surface-plot	15 300
S3411	12 August	ICE	pre-test	surface-plot	8 800
S3501-2	13 August	ID(E)C	pre-test	surface-top	21 200
S3501-4	13 August	ID(E)C	pre-test	surface-middle	70
S3501-6	13 August	ID(E)C	pre-test	surface-plot	4 360
S3502-2	13 August	ID(E)C	pre-test	subsurface-top	30
S3502-4	13 August	ID(E)C	pre-test	subsurface-middle	DL
S3502-6	13 August	ID(E)C	pre-test	subsurface-plot	5 440
S3503-2	13 August	ID(E)E	pre-test	surface-top	2 080
S3503-4	13 August	ID(E)E	pre-test	surface-middle	690
S3503-6	13 August	ID(E)E	pre-test	surface-plot	1 680
S3504-2	13 August	ID(E)E	pre-test	subsurface-top	DL
S3504-4	13 August	ID(E)E	pre-test	subsurface-middle	DL
S3504-6	13 August	ID(E)E	pre-test	subsurface-plot	DL
S3505-2	13 August	ID(B)C	pre-test	surface-top	9 690
S3505-4	13 August	ID(B)C	pre-test	surface-middle	2 860
S3505-6	13 August	ID(B)C	pre-test	surface-plot	840
S3506-2	13 August	ID(B)C	pre-test	subsurface-top	370
S3506-4	13 August	ID(B)C	pre-test	subsurface-middle	DL
S3506-6	13 August	ID(B)C	pre-test	subsurface-plot	50
S3507-2	13 August	ID(B)E	pre-test	surface-top	5 220
S3507-4	13 August	ID(B)E	pre-test	surface-middle	540
S3507-6	13 August	ID(B)E	pre-test	surface-plot	7 340
S3508-2	13 August	ID(B)E	pre-test	subsurface-top	DL
S3508-4	13 August	ID(B)E	pre-test	subsurface-middle	DL
S3508-6	13 August	ID(B)E	pre-test	subsurface-plot	410
S3509-2	13 August	ICC	pre-test	surface-top	11 000
S3509-4	13 August	ICC	pre-test	surface-middle	160
S3509-6	13 August	ICC	pre-test	surface-plot	1 460
S3510-2	13 August	ICC	pre-test	subsurface-top	50
S3510-4	13 August	ICC	pre-test	subsurface-middle	DL
S3510-6	13 August	ICC	pre-test	subsurface-plot	40

TABLE B.4 (Cont'd.)

Sample No.	Date	Plot	Sample Schedule	Location	t-h (mg/kg)
S3511-2	13 August	ICE	pre-test	surface-top	1 730
S3511-4	13 August	ICE	pre-test	surface-middle	270
S3511-6	13 August	ICE	pre-test	surface-plot	6 330
S3512-2	13 August	ICE	pre-test	subsurface-top	DL
S3512-4	13 August	ICE	pre-test	subsurface-middle	DL
S3512-6	13 August	ICE	pre-test	subsurface-plot	90
S3513	14 August	IMC-e	pre-test	surface-back beach	23 800
S3514	14 August	IMC-e	pre-test	surface-berm	106 000
S3515	14 August	IME-c	pre-test	surface-back beach	42 200
S3516	14 August	IME-c	pre-test	surface-berm	17 100
S3517	14 August	IMC-c	pre-test	surface-back beach	24 200
S3518	14 August	IMC-c	pre-test	surface-berm	56 500
S3519	14 August	IME-e	pre-test	surface-back beach	18 400
S3520	14 August	IME-e	pre-test	surface-berm	12 400
S3521	14 August	IMC-e	pre-test	subsurface-back beach	100
S3522	14 August	IMC-e	pre-test	subsurface-berm	2 200
S3523	14 August	IME-c	pre-test	subsurface-back beach	360
S3524	14 August	IME-c	pre-test	subsurface-berm	17 900
S3525	14 August	IMC-c	pre-test	subsurface-back beach	270
S3526	14 August	IMC-c	pre-test	subsurface-berm	7 010
S3527	14 August	IME-e	pre-test	subsurface-back beach	140
S3528	14 August	IME-e	pre-test	subsurface-berm	14 500
S3603-2E	14 August	ICE	post-test	surface-top	11 000
S3603-3E	14 August	ICE	post-test	surface-upper	9 660
S3603-4E	14 August	ICE	post-test	surface-middle	430
S3603-6E	14 August	ICE	post-test	surface-plot	24 000
S3603-2W	14 August	ICE	post-test	surface-top	1 600
S3603-3W	14 August	ICE	post-test	surface-upper	2 390
S3603-4W	14 August	ICE	post-test	surface-middle	310
S3603-6W	14 August	ICE	post-test	surface-plot	5 410
S3604-2E	14 August	ICE	post-test	subsurface-top	DL
S3604-3E	14 August	ICE	post-test	subsurface-upper	90
S3604-4E	14 August	ICE	post-test	subsurface-middle	DL
S3604-6E	14 August	ICE	post-test	subsurface-plot	40
S3604-2W	14 August	ICE	post-test	subsurface-top	30
S3604-3W	14 August	ICE	post-test	subsurface-upper	50
S3604-4W	14 August	ICE	post-test	subsurface-middle	DL
S3604-6W	14 August	ICE	post-test	subsurface-plot	80

TABLE B.4 (Cont'd.)

Sample No.	Date	Plot	Sample Schedule	Location	t-h (mg/kg)
S3605-2	14 August	ID(B)C	post-test	surface-top	20 400
S3605-4	14 August	ID(B)C	post-test	surface-middle	18 500
S3605-6	14 August	ID(B)C	post-test	surface-plot	30
S3605-3	14 August	ID(B)C	post-test	surface-upper	8 300
S3606-2	14 August	ID(B)C	post-test	subsurface-top	200
S3606-3	14 August	ID(B)C	post-test	subsurface-upper	40
S3606-4	14 August	ID(B)C	post-test	subsurface-middle	7 130
S3606-6	14 August	ID(B)C	post-test	subsurface-plot	DL
S3607-2	14 August	ID(B)E	post-test	surface-top	40 900
S3607-3	14 August	ID(B)E	post-test	surface-upper	34 000
S3607-4	14 August	ID(B)E	post-test	surface-middle	8 960
S3607-6	14 August	ID(B)E	post-test	surface-plot	20 200
S3608-2	14 August	ID(B)E	post-test	subsurface-top	1 320
S3608-3	14 August	ID(B)E	post-test	subsurface-upper	30
S3608-4	14 August	ID(B)E	post-test	subsurface-middle	60
S3608-6	14 August	ID(B)E	post-test	subsurface-plot	50
S3609-2	14 August	ID(E)C	post-test	surface-top	12 800
S3609-3	14 August	ID(E)C	post-test	surface-upper	1 980
S3609-4	14 August	ID(E)C	post-test	surface-middle	130
S3609-6	14 August	ID(E)C	post-test	surface-plot	420
S3610-2	14 August	ID(E)C	post-test	subsurface-top	40
S3610-3	14 August	ID(E)C	post-test	subsurface-upper	DL
S3610-4	14 August	ID(E)C	post-test	subsurface-middle	DL
S3610-6	14 August	ID(E)C	post-test	subsurface-plot	460
S3611-2	14 August	ID(E)E	post-test	surface-top	2 160
S3611-3	14 August	ID(E)E	post-test	surface-upper	1 320
S3611-4	14 August	ID(E)E	post-test	surface-middle	230
S3611-6	14 August	ID(E)E	post-test	surface-plot	1 520
S3612-2	14 August	ID(E)E	post-test	subsurface-top	100
S3612-3	14 August	ID(E)E	post-test	subsurface-upper	30
S3612-4	14 August	ID(E)E	post-test	subsurface-middle	DL
S3612-6	14 August	ID(E)E	post-test	subsurface-plot	DL
S3613	15 August	IMC-e	post-test	surface-back beach	20 600
S3614	15 August	IMC-e	post-test	surface-berm	66 900
S3615	15 August	IME-c	post-test	surface-back beach	12 300
S3616	15 August	IME-c	post-test	surface-berm	9 270
S3617	15 August	IMC-c	post-test	surface-back beach	12 700
S3618	15 August	IMC-c	post-test	surface-berm	23 200
S3619	15 August	IME-e	post-test	surface-back beach	34 500
S3620	15 August	IME-e	post-test	surface-berm	7 730

TABLE B.4 (Cont'd.)

Sample No.	Date	Plot	Sample Schedule	Location	t-h (mg/kg)
S3621	15 August	IMC-e	post-test	subsurface-back beach	570
S3622	15 August	IMC-e	post-test	subsurface-berm	1 420
S3623	15 August	IME-c	post-test	subsurface-back beach	11 900
S3624	15 August	IME-c	post-test	subsurface-berm	12 600
S3625	15 August	IMC-c	post-test	subsurface-back beach	8 400
S3626	15 August	IMC-c	post-test	subsurface-berm	missing
S3627	15 August	IME-e	post-test	subsurface-back beach	120
S3628	15 August	IME-e	post-test	subsurface-berm	11 200
S3703-2E	20 August	ICE	+7	surface-top	1 170
S3703-3E	20 August	ICE	+7	surface-upper	33 600
S3703-4E	20 August	ICE	+7	surface-middle	460
S3703-6E	20 August	ICE	+7	surface-plot	15 900
S3703-1E	20 August	ICE	+7	surface-highest	70
S3703-2W	20 August	ICE	+7	surface-top	230
S3703-3W	20 August	ICE	+7	surface-upper	1 040
S3703-4W	20 August	ICE	+7	surface-middle	260
S3703-6W	20 August	ICE	+7	surface-plot	4 630
S3703-1W	20 August	ICE	+7	surface-highest	50
S3704-2E	20 August	ICE	+7	subsurface-top	DL
S3704-3E	20 August	ICE	+7	subsurface-upper	30
S3704-4E	20 August	ICE	+7	subsurface-middle	DL
S3704-6E	20 August	ICE	+7	subsurface-plot	30
S3704-1E	20 August	ICE	+7	subsurface-highest	DL
S3704-2W	20 August	ICE	+7	subsurface-top	DL
S3704-3W	20 August	ICE	+7	subsurface-upper	DL
S3704-4W	20 August	ICE	+7	subsurface-middle	DL
S3704-6W	20 August	ICE	+7	subsurface-plot	DL
S3704-1W	20 August	ICE	+7	subsurface-highest	DL
S3701-2	20 August	ICC	+7	surface-top	6 860
S3701-3	20 August	ICC	+7	surface-upper	620
S3701-4	20 August	ICC	+7	surface-middle	100
S3701-6	20 August	ICC	+7	surface-plot	5 240
S3701-1	20 August	ICC	+7	surface-highest	missing
S3702-2	20 August	ICC	+7	subsurface-top	DL
S3702-3	20 August	ICC	+7	subsurface-upper	DL
S3702-4	20 August	ICC	+7	subsurface-middle	DL
S3702-6	20 August	ICC	+7	subsurface-plot	DL
S3702-1	20 August	ICC	+7	subsurface-highest	DL
S3705-2	20 August	ID(B)C	+7	surface-top	27 900
S3705-3	20 August	ID(B)C	+7	surface-upper	10 500
S3705-4	20 August	ID(B)C	+7	surface-middle	5 060
S3705-6	20 August	ID(B)C	+7	surface-plot	2 960
S3705-1	20 August	ID(B)C	+7	surface-highest	1 140

TABLE B.4 (Cont'd.)

Sample No.	Date	Plot	Sample Schedule	Location	t-h (mg/kg)
S3706-2	20 August	ID(B)C	+7 days	subsurface-top	70
S3706-3	20 August	ID(B)C	+7	subsurface-upper	50
S3706-4	20 August	ID(B)C	+7	subsurface-middle	DL
S3706-6	20 August	ID(B)C	+7	subsurface-plot	DL
S3706-1	20 August	ID(B)C	+7	subsurface-highest	DL
S3707-2	20 August	ID(B)E	+7	surface-top	29 100
S3707-3	20 August	ID(B)E	+7	surface-upper	6 340
S3707-4	20 August	ID(B)E	+7	surface-middle	4 810
S3707-6	20 August	ID(B)E	+7	surface-plot	11 800
S3707-1	20 August	ID(B)E	+7	surface-highest	390
S3708-2	20 August	ID(B)E	+7	subsurface-top	30
S3708-3	20 August	ID(B)E	+7	subsurface-upper	DL
S3708-4	20 August	ID(B)E	+7	subsurface-middle	DL
S3708-6	20 August	ID(B)E	+7	subsurface-plot	DL
S3708-1	20 August	ID(B)E	+7	subsurface-highest	DL
S3709-2	20 August	ID(E)C	+7	surface-top	8 770
S3709-3	20 August	ID(E)C	+7	surface-upper	930
S3709-4	20 August	ID(E)C	+7	surface-middle	260
S3709-6	20 August	ID(E)C	+7	surface-plot	120
S3709-1	20 August	ID(E)C	+7	surface-highest	80
S3710-2	20 August	ID(E)C	+7	subsurface-top	DL
S3710-3	20 August	ID(E)C	+7	subsurface-upper	50
S3710-4	20 August	ID(E)C	+7	subsurface-middle	DL
S3710-6	20 August	ID(E)C	+7	subsurface-plot	DL
S3710-1	20 August	ID(E)C	+7	subsurface-highest	DL
S3711-2	20 August	ID(E)E	+7	surface-top	15 200
S3711-3	20 August	ID(E)E	+7	surface-upper	2 180
S3711-4	20 August	ID(E)E	+7	surface-middle	530
S3711-6	20 August	ID(E)E	+7	surface-plot	1 510
S3711-1	20 August	ID(E)E	+7	surface-highest	910
S3712-2	20 August	ID(E)E	+7	subsurface-top	100
S3712-3	20 August	ID(E)E	+7	subsurface-upper	DL
S3712-4	20 August	ID(E)E	+7	subsurface-middle	DL
S3712-6	20 August	ID(E)E	+7	subsurface-plot	DL
S3712-1	20 August	ID(E)E	+7	subsurface-highest	DL
S3713	22 August	IMC-e	+7	surface-back beach	38 200
S3714	22 August	IMC-e	+7	surface-berm	88 600
S3715	22 August	IME-c	+7	surface-back beach	24 800
S3716	22 August	IME-c	+7	surface-berm	13 800
S3717	22 August	IMC-c	+7	surface-back beach	14 500
S3718	22 August	IMC-c	+7	surface-berm	18 700
S3719	22 August	IME-e	+7	surface-back beach	40 000
S3720	22 August	IME-e	+7	surface-berm	8 640

TABLE B.4 (Cont'd.)

Sample No.	Date	Plot	Sample Schedule	Location	t-h (mg/kg)
S3721	22 August	IMC-e	+7 days	subsurface-back beach	170
S3722	22 August	IMC-e	+7	subsurface-berm	1 860
S3723	22 August	IME-c	+7	subsurface-back beach	15 100
S3724	22 August	IME-c	+7	subsurface-berm	7 670
S3725	22 August	IMC-c	+7	subsurface-back beach	9 400
S3726	22 August	IMC-c	+7	subsurface-berm	26 900
S3727	22 August	IME-e	+7	subsurface-back beach	220
S3728	22 August	IME-e	+7	subsurface-berm	11 500
S3801-2	15 September	ICC	+33	surface-top	200
S3801-3	15 September	ICC	+33	surface-upper	650
S3801-4	15 September	ICC	+33	surface-middle	620
S3801-6	15 September	ICC	+33	surface-plot	2 130
S3801-1	15 September	ICC	+33	surface-highest	400
S3802-2	15 September	ICC	+33	subsurface-top	50
S3802-3	15 September	ICC	+33	subsurface-upper	420
S3802-4	15 September	ICC	+33	subsurface-middle	DL
S3802-6	15 September	ICC	+33	subsurface-plot	DL
S3802-1	15 September	ICC	+33	subsurface-highest	50
S3803-2E	15 September	ICE	+33	surface-top	1 370
S3803-3E	15 September	ICE	+33	surface-upper	15 100
S3803-4E	15 September	ICE	+33	surface-middle	1 180
S3803-6E	15 September	ICE	+33	surface-plot	11 900
S3803-1E	15 September	ICE	+33	surface-highest	40
S3803-2W	15 September	ICE	+33	surface-top	8 210
S3803-3W	15 September	ICE	+33	surface-upper	530
S3803-4W	15 September	ICE	+33	surface-middle	200
S3803-6W	15 September	ICE	+33	surface-plot	830
S3803-1W	15 September	ICE	+33	surface-highest	230
S3804-2E	15 September	ICE	+33	subsurface-top	190
S3804-3E	15 September	ICE	+33	subsurface-upper	180
S3804-4E	15 September	ICE	+33	subsurface-middle	90
S3804-6E	15 September	ICE	+33	subsurface-plot	270
S3804-1E	15 September	ICE	+33	subsurface-highest	missing
S3804-2W	15 September	ICE	+33	subsurface-top	5 720
S3804-3W	15 September	ICE	+33	subsurface-upper	DL
S3804-4W	15 September	ICE	+33	subsurface-middle	DL
S3804-6W	15 September	ICE	+33	subsurface-plot	DL
S3804-1W	15 September	ICE	+33	subsurface-highest	30
S3805-2	15 September	ID(B)C	+33	surface-top	12 300
S3805-3	15 September	ID(B)C	+33	surface-upper	1 730
S3805-4	15 September	ID(B)C	+33	surface-middle	3 240
S3805-6	15 September	ID(B)C	+33	surface-plot	170
S3805-1	15 September	ID(B)C	+33	surface-highest	320

TABLE B.4 (Cont'd.)

Sample No.	Date	Plot	Sample Schedule	Location	t-h (mg/kg)
S3806-2	15 September	ID(B)C	+33 days	subsurface-top	2 300
S3806-3	15 September	ID(B)C	+33	subsurface-upper	2 230
S3806-4	15 September	ID(B)C	+33	subsurface-middle	3 240
S3806-6	15 September	ID(B)C	+33	subsurface-plot	210
S3806-1	15 September	ID(B)C	+33	subsurface-highest	30
S3807-2	15 September	ID(B)E	+33	surface-top	6 870
S3807-3	15 September	ID(B)E	+33	surface-upper	1 810
S3807-4	15 September	ID(B)E	+33	surface-middle	1 590
S3807-6	15 September	ID(B)E	+33	surface-plot	690
S3807-1	15 September	ID(B)E	+33	surface-highest	530
S3808-2	15 September	ID(B)E	+33	subsurface-top	7 910
S3808-3	15 September	ID(B)E	+33	subsurface-upper	360
S3808-4	15 September	ID(B)E	+33	subsurface-middle	4 340
S3808-6	15 September	ID(B)E	+33	subsurface-plot	260
S3808-1	15 September	ID(B)E	+33	subsurface-highest	150
S3809-2	15 September	ID(E)C	+33	surface-top	5 530
S3809-3	15 September	ID(E)C	+33	surface-upper	270
S3809-4	15 September	ID(E)C	+33	surface-middle	1 290
S3809-6	15 September	ID(E)C	+33	surface-plot	30
S3809-1	15 September	ID(E)C	+33	surface-highest	330
S3810-2	15 September	ID(E)C	+33	subsurface-top	1 270
S3810-3	15 September	ID(E)C	+33	subsurface-upper	2 530
S3810-4	15 September	ID(E)C	+33	subsurface-middle	DL
S3810-6	15 September	ID(E)C	+33	subsurface-plot	DL
S3810-1	15 September	ID(E)C	+33	subsurface-highest	DL
S3811-2	15 September	ID(E)E	+33	surface-top	1 520
S3811-3	15 September	ID(E)E	+33	surface-upper	380
S3811-4	15 September	ID(E)E	+33	surface-middle	1 200
S3811-6	15 September	ID(E)E	+33	surface-plot	190
S3811-1	15 September	ID(E)E	+33	surface-highest	450
S3812-2	15 September	ID(E)E	+33	subsurface-top	DL
S3812-3	15 September	ID(E)E	+33	subsurface-upper	200
S3812-4	15 September	ID(E)E	+33	subsurface-middle	30
S3812-6	15 September	ID(E)E	+33	subsurface-plot	DL
S3812-1	15 September	ID(E)E	+33	subsurface-highest	DL
S3813	15 September	IMC-e	+31	surface-back beach	32 600
S3814	15 September	IMC-e	+31	surface-berm	57 100
S3815	15 September	IME-c	+31	surface-back beach	16 700
S3816	15 September	IME-c	+31	surface-berm	8 510
S3817	15 September	IMC-c	+31	surface-back beach	18 200
S3818	15 September	IMC-c	+31	surface-berm	31 100
S3819	15 September	IME-e	+31	surface-back beach	65 200
S3820	15 September	IME-e	+31	surface-berm	5 350

TABLE B.4 (Cont'd.)

Sample No.	Date	Plot	Sample Schedule	Location	t-h (mg/kg)
S3821	15 September	IMC-e	+31	subsurface-back beach	590
S3822	15 September	IMC-e	+31	subsurface-berm	7 380
S3823	15 September	IME-c	+31	subsurface-back beach	15 000
S3824	15 September	IME-c	+31	subsurface-berm	11 500
S3825	15 September	IMC-c	+31	subsurface-back beach	7 510
S3826	15 September	IMC-c	+31	subsurface-berm	22 500
S3827	15 September	IME-e	+31	subsurface-back beach	3 050
S3828	15 September	IME-e	+31	subsurface-berm	12 800

miscellaneous samples

Sample No.	Date	Plot	Location	t-h (mg/kg)
S3132	12 August	ID(E)E	S.E. corner	27 100
S3133	12 August	ICC	S.E. corner	39 100
S3134	12 August	ICE	S.E. corner	61 000
S3135	12 August	ID(E)C	S.E. corner	56 800
S3145	12 August	ID(B)C	S.E. corner	70 700
S3146	12 August	ID(B)E	S.E. corner	6 050
S3950	13 August	IMC	back beach (S.W.) 0-0.5 cm	27 100
S3951	13 August	IMC	berm (N.W.) 0-10 cm	62 900
S3952	13 August	IME	back beach (S.E.) 0-0.5 cm	10 200
S3953	13 August	IME	berm (N.E.) 0-10 cm	44 400

TABLE B.5 Results of Analyses from Samples Collected during 1982 from "Z-Lagoon" Intertidal Sediments

Sample No.	Date	Location	t-h (mg/kg)
S3301	10 August	Z7 upper	30
S3302	10 August	Z7 middle	DL
S3303	10 August	Z7 lower	DL
S3304	10 August	Z8 upper	DL
S3305	10 August	Z8 middle	DL
S3306	10 August	Z8 lower	DL
S3307	10 August	Z9 upper	DL
S3308	10 August	Z9 middle	DL
S3309	10 August	Z9 lower	DL
S3310	10 August	Z1 upper	DL
S3311	10 August	Z1 middle	DL
S3312	10 August	Z1 lower	DL
S3313	10 August	Z2 upper	30
S3314	10 August	Z2 middle	DL
S3315	10 August	Z2 lower	30
S3316	10 August	Z3 upper	DL
S3317	10 August	Z3 middle	DL
S3318	10 August	Z3 lower	DL
S3319	10 August	Z6 upper	DL
S3320	10 August	Z6 middle	DL
S3321	10 August	Z6 lower	DL
S3322	10 August	Z5 upper	DL
S3323	10 August	Z5 middle	DL
S3324	10 August	Z5 lower	DL
S3325	10 August	Z4 upper	30
S3326	10 August	Z4 middle	150
S3327	10 August	Z4 lower	DL

TABLE B.6 Results of Analyses from Samples Collected during 1982 from the Beaches of Ragged Channel

Sample No.	Date	Location	Position	t-h (mg/kg)
S3201	12 August	Bay 9 - profile 100	upper-surface	DL
S3202	12 August	Bay 9 - profile 100	upper-subsurface	DL
S3203	12 August	Bay 9 - profile 100	middle-surface	DL
S3204	12 August	Bay 9 - profile 100	middle-subsurface	DL
S3205	12 August	Bay 9 - profile 100	lower-surface	DL
S3206	12 August	Bay 9 - profile 100	lower-subsurface	DL
S3207	12 August	Bay 9 - profile 300	upper-surface	DL
S3208	12 August	Bay 9 - profile 300	upper-subsurface	DL
S3209	12 August	Bay 9 - profile 300	middle-surface	DL
S3210	12 August	Bay 9 - profile 300	middle-subsurface	DL
S3211	12 August	Bay 9 - profile 300	lower-surface	DL
S3212	12 August	Bay 9 - profile 300	lower-subsurface	DL
S3213	12 August	Bay 9 - profile 600	upper-surface	DL
S3214	12 August	Bay 9 - profile 600	upper-subsurface	DL
S3215	12 August	Bay 9 - profile 600	middle-surface	DL
S3216	12 August	Bay 9 - profile 600	middle-subsurface	DL
S3217	12 August	Bay 9 - profile 600	lower-surface	DL
S3218	12 August	Bay 9 - profile 600	lower-subsurface	DL
S3221	10 August	Bay 11 - profile 2	upper-surface	3 370
S3222	10 August	Bay 11 - profile 2	upper-subsurface	1 180
S3223	10 August	Bay 11 - profile 2	middle-surface	4 040
S3224	10 August	Bay 11 - profile 2	middle-subsurface	270
S3225	10 August	Bay 11 - profile 2	lower-surface	860
S3226	10 August	Bay 11 - profile 2	lower-subsurface	60
S3227	10 August	Bay 11 - profile 4	upper-surface	9 730
S3228	10 August	Bay 11 - profile 4	upper-subsurface	1 500
S3229	10 August	Bay 11 - profile 4	middle-surface	2 690
S3230	10 August	Bay 11 - profile 4	middle-subsurface	540
S3231	10 August	Bay 11 - profile 4	lower-surface	620
S3232	10 August	Bay 11 - profile 4	lower-subsurface	160
S3233	10 August	Bay 11 - profile 7	upper-surface	11 800
S3234	10 August	Bay 11 - profile 7	upper-subsurface	5 250
S3235	10 August	Bay 11 - profile 7	middle-surface	2 190
S3236	10 August	Bay 11 - profile 7	middle-subsurface	120
S3237	10 August	Bay 11 - profile 7	lower-surface	4 080
S3238	10 August	Bay 11 - profile 7	lower-subsurface	160

APPENDIX C - GEOCHEMICAL ANALYSES DATA

The data presented in this Appendix were prepared by Energy Resources Co., Inc. (ERCO). A detailed account of the procedures and an interpretation of these data are included in Boehm (1983). Hydrocarbon values are expressed as mg/kg (p.p.m.) except where noted.

The 1982 data sets presented in this Appendix are as follows:

Table C.1	1980 Control Plots
Table C.2	1981 Crude Oil Point Plots
Table C.3	1982 Bay 106 Plots
	(a) Barrel samples
	(b) Intertidal samples
	(c) Backshore samples
Table C.4	Ragged Channel Beaches

Table C.1 Geochemical Analyses Results: 1980 Control Plots

PLOT	DATE	CONCENTRATIONS (mg/g) TOTAL EXTRACTABLES	SATURATED HYDROCARBONS Resolved	SATURATED HYDROCARBONS Total	AROMATIC HYDROCARBONS Resolved	AROMATIC HYDROCARBONS Total	DIAGNOSTIC RATIOS SHWR	DIAGNOSTIC RATIOS ALK/ISO	DIAGNOSTIC RATIOS AWR
H1 (C)	10 Aug 82	.0047	.0001	.0008	<.0001	.0016	1.8	1.4	
H2 (E)	10 Aug 82	.0055	.0002	.0007	<.0001	.0010	1.7	1.4	
L1 (C)	10 Aug 82	2.71	0.180	1.06	0.014	0.75	1.3	1.7	not detected
L2 (E)	10 Aug 82	.0127	.0005	.0022	<.0001	.0021	1.1	1.1	1.1
T1 (C)	10 Aug 82	26.4	2.64	11.7	0.27	7.05	1.6	2.4	1.9
T2 (E)	10 Aug 82	15.8	1.21	6.67	0.10	4.19	1.3	2.4	1.3
TE1 (C)	10 Aug 82	30.9	6.67	10.4	1.04	9.90	3.4	2.6	
TE2 (E)	10 Aug 82	12.3	3.03	8.02	0.32	6.45	2.0	2.5	

(C) - crude

(E) - emulsion

note:
mg/g = p.p.t.

Table C.2 Geochemical Analyses Results: 1981 Countermeasure Plots

PLOT	DATE	CONCENTRATIONS (mg/kg) TOTAL EXTRACTABLES	SATURATED HYDROCARBONS Resolved	SATURATED HYDROCARBONS Total	AROMATIC HYDROCARBONS Resolved	AROMATIC HYDROCARBONS Total	DIAGNOSTIC RATIOS SHWR	DIAGNOSTIC RATIOS ALK/ISO	DIAGNOSTIC RATIOS AWR
D(E) E	8 Aug 82	138.0	19.9	53.0	0.99	46.0	2.6	3.0	1.5
	29 Aug 82	14.6	0.7	5.0	0.07	3.1	1.4	2.2	
D(E) C	8 Aug 82	87.8	7.4	32.0	0.55	21.0	2.4	3.2	not detected
	29 Aug 82	40.5	2.2	14.0	0.12	10.0	1.1	1.2	
ME	8 Aug 82	60.0	17.6+	32.0	0.33	9.0	12.1+	4.7+	not detected
	29 Aug 82	82.0	6.7	26.0	0.20	16.0	1.0	1.1	
MC	8 Aug 82	140.0	11.6	52.0	0.59	42.0	1.9	1.9	
	29 Aug 82	53.0	2.4	19.0	0.15	13.0	1.1	1.7	
CE	8 Aug 82	84.0	7.0	33.0	0.32	20.0	1.1	1.6	
	29 Aug 82	111.0	16.8	51.0	0.36	28.0	1.0	1.5	
CC	8 Aug 82	136.0	13.1	51.0	0.50	32.0	1.3	2.2	
	29 Aug 82	41.4	4.2	14.0	0.11	8.6	1.1	1.6	
D(B) E	8 Aug 82	10.0	0.64	2.1	0.03	2.8	2.7	2.2	
	29 Aug 82	4.4	0.11	0.6	0.02	1.6	1.8	2.2	
D(B) C	8 Aug 82	9.9	0.17	1.3	0.04	2.6	1.5	1.2	
	29 Aug 82	3.5	0.05	0.5	0.02	1.0	1.8	0.71	

+Sample appears to have been contaminated; values are suspect.

Table C.3 Geochemical Analyses Results: 1982 Countermeasure Plots
(a) Barrel Oil Samples

PLOT	DATE	CONCENTRATIONS (mg/g) TOTAL EXTRACTABLES	SATURATED HYDROCARBONS Resolved	SATURATED HYDROCARBONS Total	AROMATIC HYDROCARBONS Resolved	AROMATIC HYDROCARBONS Total	DIAGNOSTIC RATIOS SHWR	DIAGNOSTIC RATIOS ALK/ISO	DIAGNOSTIC RATIOS AWR
ID(B) C	12 Aug 82	767.0		382.0		315.0	2.7	2.6	
ID(B) E	12 Aug 82	356.0		179.0		123.0	3.6	2.6	
ID(E) C	12 Aug 82	804.0		313.0		315.0	3.6	2.6	
ID(E) E	12 Aug 82	328.0		132.0		112.0	3.4	2.6	
ICC	12 Aug 82	766.0		350.0		312.0	3.2	2.7	2.0
ICE	12 Aug 82	290.0		119.0		106.0	2.9	2.6	2.0
IMC	13 Aug 82	743.0		383.0		280.0	3.6	2.7	1.9

note:
mg/g = p.p.t.

Table C.3 Geochemical Analyses Results: 1982 Countermeasure Plots
(b) Post-Test Samples- Intertidal Plots

PLOT	DATE	ROW	CONCENTRATIONS (mg/g) TOTAL EXTRACTABLES	SATURATED HYDROCARBONS Resolved	SATURATED HYDROCARBONS Total	AROMATIC HYDROCARBONS Resolved	AROMATIC HYDROCARBONS Total	DIAGNOSTIC RATIOS SHWR	DIAGNOSTIC RATIOS ALK/ISO	DIAGNOSTIC RATIOS AWR
ID(B) C	14 Aug 82	2	19.4	9.54	13.7	0.18	2.2	34.0	5.6	
	14 Aug 82	6	3.6	1.55	3.0	0.08	0.53	17.0	5.2	
	20 Aug 82	2	18.6	2.60	12.0	0.30	3.6	9.3	4.6	
	15 Sep 82	2	10.4	2.25	6.5	0.09	1.5	16.0	4.6	
ID(B) E	14 Aug 82	2	20.4	2.91	15.6	0.47	2.6	26.0	4.6	
	14 Aug 82	6	13.5	4.63	8.5	0.24	2.0	14.0	5.2	
	20 Aug 82	2	14.4	6.51	10.0	0.24	1.8	21.0	5.2	
	15 Sep 82	2	5.17	1.16	3.6	0.06	0.71	16.0	4.6	
ID(E) C	14 Aug 82	2	13.7	1.53	6.6	0.23	4.9	2.0	2.6	
	14 Aug 82	6	0.27	0.036	0.12	0.006	0.09	1.8	2.6	
	20 Aug 82	2	11.9	1.38	5.1	0.13	3.4	2.1	2.6	
	15 Sep 82	2	11.1	1.19	4.4	0.12	3.3	1.7	2.6	
ID(E) E	14 Aug 82	2	2.74	0.20	0.98	0.028	0.72	2.0	2.8	
	14 Aug 82	6	1.45	0.14	0.53	0.021	0.38	2.2	2.6	
	20 Aug 82	2	14.5	1.62	6.9	0.18	4.2	1.9	2.7	
	15 Sep 82	2	6.78	0.65	2.5	0.051	2.0	1.4	2.6	
ICC	20 Aug 82	2	2.03	0.22	0.87	0.024	0.53	1.9	2.6	1.7
	15 Sep 82	2	0.28	0.031	0.13	0.002	0.08	1.6	2.8	1.5
ICE	20 Aug 82	2	0.22	0.024	0.09	0.002	0.06	1.6	2.6	1.3
	15 Sep 82	2	2.28	0.22	0.84	0.025	0.61	1.8	2.7	1.7

note:
mg/g = p.p.t.

Table C.3 Geochemical Analyses Results: 1982 Countermeasure Plots (c) Post-Test Samples - Backshore Plots

PLOT	DATE	CONCENTRATIONS (mg/g) TOTAL EXTRACTABLES	SATURATED HYDROCARBONS Resolved	SATURATED HYDROCARBONS Total	AROMATIC HYDROCARBONS Resolved	AROMATIC HYDROCARBONS Total	DIAGNOSTIC RATIOS SHWR	DIAGNOSTIC RATIOS ALK/ISO	DIAGNOSTIC RATIOS AWR
IMC-e	15 Aug 82	45.8	5.38	21.6	0.96	16.3	2.0	2.6	
	22 Aug 82	45.8	5.10	17.3	0.68	12.3	2.2	2.7	
	15 Sep 82	3.8	0.40	1.2	0.03	0.38	1.7	2.6	
IMC-c	15 Aug 82	19.2	2.52	7.5	0.37	5.7	2.6	2.5	2.3
	22 Aug 82	18.9	2.23	8.3	0.27	5.5	2.0	2.7	2.0
	15 Sep 82	8.9	0.96	3.3	0.11	1.1	2.0	2.6	2.0
IME-e	15 Aug 82	16.8	1.97	7.2	0.30	4.8	2.3	2.6	
	22 Aug 82	31.2	3.11	10.9	0.40	8.0	1.8	2.9	
	15 Sep 82	16.2	1.96	6.0	0.23	1.8	2.0	2.6	
IME-c	15 Aug 82	13.7	1.80	6.1	0.33	4.1	2.3	2.6	2.1
	22 Aug 82	13.9	1.38	5.9	0.16	3.6	2.0	2.6	2.0
	15 Sep 82	1.4	0.13	0.42	0.01	0.15	1.6	2.4	1.7

e - end
c - centre

note:
mg/g = p.p.t.

Table C.4 Geochemcial Analyses Results: Ragged Channel Sites

	PLOT	DATE	CONCENTRATIONS (mg/kg) TOTAL EXTRACTABLES	SATURATED HYDROCARBONS Resolved	SATURATED HYDROCARBONS Total	AROMATIC HYDROCARBONS Resolved	AROMATIC HYDROCARBONS Total	DIAGNOSTIC RATIOS SHWR	DIAGNOSTIC RATIOS ALK/ISO	DIAGNOSTIC RATIOS AWR
BAY 9	P100-U	8 Aug 82	2.30	0.08	0.2	0.01	1.1	1.1	1.9	
	P100-M	8 Aug 82	2.80	0.17	0.5	0.03	0.7	1.3	3.6	
	P100-L	8 Aug 82	26.9	3.38	12.0	0.15	9.2	1.1	2.2	
	P300-U	8 Aug 82	1.90	0.06	0.2	0.02	1.1	1.6	2.8	
	P300-M	8 Aug 82	3.10	0.22	0.6	0.06	0.5	1.7	3.9	
	P300-L	8 Aug 82	1.80	0.11	0.2	0.03	0.6	1.5	3.9	
BAY 11	P2-U	8 Aug 82	2140.0	125.0	1250.0	9.0	880.0	1.0	1.0	
	P2-M	8 Aug 82	5790.0	277.0	2030.0	24.6	1640.0	1.2	1.1	
	P2-L	8 Aug 82	1230.0	52.9	420.0	3.7	280.0	1.1	0.6	
	P6-U	8 Aug 82	9870.0	849.0	4230.0	53.3	2990.0	1.2	1.8	
	P6-M	8 Aug 82	2850.0	119.0	1030.0	10.2	610.0	1.1	0.9	
	P6-L	8 Aug 82	6460.0	351.0	2420.0	29.1	1940.0	1.2	1.3	

U,M,L = upper, middle, and lower thirds of the intertidal zone

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